TECHNICAL REPORT
68-55-AD

PRELIMINARY INVESTIGATION OF TROLLEY LOW ALTITUDE AIRDROP CONCEPT

by
C. W. Miller, D. E. Alford,
H. E. Komodowski and F. H. Stokes

Lockheed-Georgia Company
(A Division of Lockheed Aircraft Corporation)
Marietta, Georgia

Contract No. DA 19-129-AMC-856 (N)

April 1968

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Airdrop Engineering Laboratory

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FOREWORD

This report summarizes the results of an operational development feasibility study of the Trolley concept which was originally developed by the Lockheed-Georgia Company of Marietta, Georgia. The work was performed for the US Army Natick Laboratories under Contract Number DA19-129-AMC-856(N) with Peter J. Macek of the Airdrop Engineering Laboratory serving as Project Officer.

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ABSTRACT

The Lockheed Trolley Low Altitude Airdrop Concept employs a towed parachute to maintain tension in a long cable from which a load may be suspended until it contacts the ground. After it is extracted by the force of the parachute, the load slides beneath the cable until it contacts the ground. Rate of descent is controlled by a winch in the aircraft that reels in the cable as needed to minimize impact velocity.

This preliminary concept-oriented investigation was undertaken to determine the feasibility of developing this system for operational use. The study consists of analytical evaluation of the operational parameters, limited component testing, and consideration of basic hardware requirements. Finalization of hardware design is not within the scope of this report. Digital and analog computer simulations of Trolley airdrop are among the analytical methods employed. Two tests of a parachute towed on a Trolley cable behind a C-130 aircraft are evaluated. Laboratory tests of certain components are analyzed with respect to flight safety.

The results of this study indicate no problems which preclude the development of the Trolley airdrop concept into an operational system for airdropping individual loads of 2,000 to 10,000 pounds from a C-130 below 500 feet. Comparison of Trolley to conventional airdrop shows: (1) costs are reduced, (2) accuracy is improved, (3) impact velocities are lower, (4) rigging is simplified. However, the system is unsuitable for mass assault where several unit loads must be dropped per aircraft pass.

PRELIMINARY INVESTIGATION OF TROLLEY LOW ALTITUDE AIRDROP CONCEPT

I. Introduction

Currently there is no operational airdrop system that provides for low altitude, high-accuracy cargo delivery with a minimum of preparation of drop site and delivered cargo. The Lockheed-Georgia Company's Trolley airdrop concept is a system devised to satisfy the above requirements and to provide a wide range of operational flexibility for airdrop aircraft.

This study, funded by the U. S. Army under Contract DA 19-129-AMC-856(N), required a detailed analytical investigation and limited component testing to provide data on the practicality of the Lockheed-conceived Trolley system. The intent of this study, therefore, is to perform a preliminary investigation of the Trolley airdrop concept with emphasis being placed on operational capability. The limited component testing is considered to be of secondary importance in this phase. Since the investigation is preliminary and concept-oriented, a major effort of the study is confined to analytical methods which include both digital and analog simulation of the Trolley concept. The digital and analog simulations were developed at Lockheed-Georgia and are used extensively in the investigations.

This study also included an evaluation of the operational characteristics of the system. The expected procedures to be used in dropping cargo by means of Trolley are of particular importance because they indicate the ease with which the system can be integrated into Army units. A brief flight test program is also included to confirm certain assumptions made concerning system operation.

II. Technical Evaluation

The technical investigation and evaluation of the Trolley airdrop concept was concerned with the following four areas.

- o Mathematical Analysis
- o Operational Analysis
- o Functional Analysis
- o Test Program

Each of the above items is discussed in detail in this section of the report.

Mathematical Analysis

Construction of a realistic mathematical model to describe Trolley airdrop requires a thorough understanding of the phases of operation of Trolley as shown in Figure 1. The system consists of a parachute trailing at the end of a long cable which passes through a slide on the drop cargo and onto a winch in the aircraft. A stop which cannot pass through the slide is attached to the cable between the drop cargo slide and the winch. When the winch brake is released, the drag of the parachute is applied to the slide by this stop, thus extracting the drop cargo from the aircraft.

For the first few seconds of drop, the cable between the drop cargo and the aircraft is allowed to pay out freely; the tension in that portion of the cable is minimal. The system in this phase is much like the extraction phase of a conventional paradrop.

After a predetermined amount of cable is payed out, the winch is quickly braked to a controlled stop, and the tension in both cable sections becomes approximately equal. Due to aerodynamic drag and the difference in line slopes, the slide from which the drop cargo is suspended begins to move toward the parachute while continuing to decelerate horizontally. Vertical velocity is arrested by the support of the cable. After the drop cargo velocity has been reduced to a satisfactory level, the winch is allowed to reel-in in order to maintain a predetermined constant cable tension. This action allows the drop cargo to maintain relatively constant vertical and horizontal velocities suitable for ground impact for several seconds, thereby reducing system sensitivity to errors in aircraft altitude.

When the drop cargo touches the ground, the slide is disconnected from the drop cargo by a standard impact release mechanism. A short time later, the slide is released from the cable when it strikes a stop

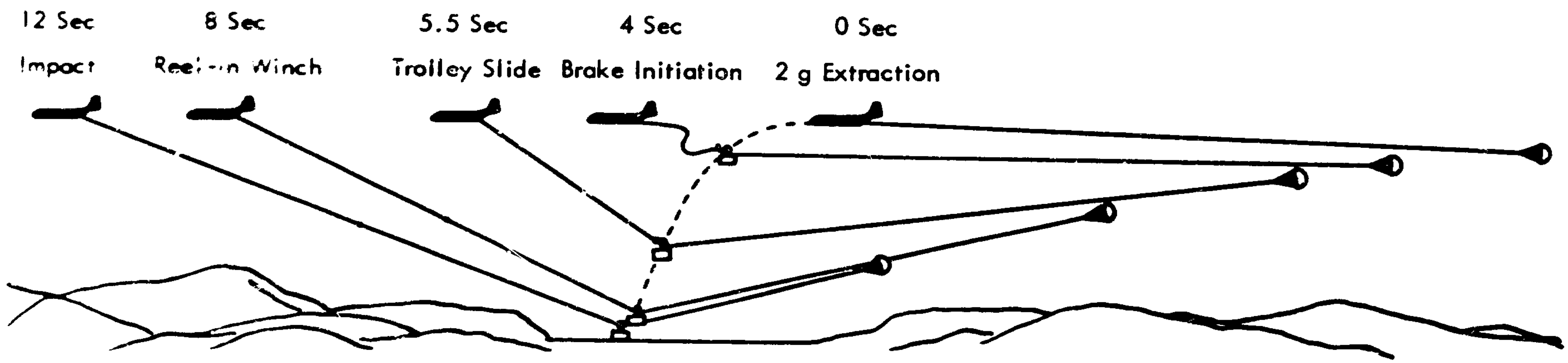

Figure 1 - Drop Sequence

placed on the cable about 10 feet from the parachute. The cable and parachute are then retrieved into the aircraft.

The mathematical simulation of this system was accomplished on both the digital and analog computers. Fewer simplifying assumptions were made in the analog simulation than were made in the digital simulation because this type problem is more easily solved on the analog computer. The primary reason for this is that aircraft response can be accounted for in a relatively simple manner on the analog computer as compared to the digital computer. Aircraft response was not included in the digital simulation.

It is interesting to note that results from both simulations agree very closely until braking of the winch occurs. This is as expected because aircraft effect on the drop is negligible until the winch is braked to a stop. In general, the trends of results from both computers are the same after braking, but actual values of some parameters are somewhat different. Results from the two computers were integrated in some cases.

Integration of the results from both computers was begun by making a base run on both the analog and digital computer with identical inputs to each. The results obtained; i.e. the horizontal and vertical impact velocities and the drop altitude, were compared and found to follow the same trends. At this point, the digital computer was used to investigate the effect of certain variables on system performance and the results were non-dimensionalized with respect to the digital base run. These non-dimensionalized digital results were then applied to the base analog results to obtain accuracy not available with the analog computer alone. This is justifiable since the trends of results from both computers are the same.

A more detailed description of both computer analyses follows

Digital Computer Investigation

The digital computer simulation of Trolley was used for the preliminary investigation of the effects of certain parameters on system operation. Since this analysis was intended for, and developed to be, an initial approximation, it is appropriate to review the basic assumptions made in order to simplify the mathematical modeling of the system.

1. The airplane flight path is unaffected by events in the drop sequence; i.e., effects of normal force pertubations on the airplane are neglected. Effects of cable tension drag components and of incremental propulsion thrust changes are accounted for.

2. Winch inertia is neglected in a strict sense but is approximately accounted for by a tension component in the winch-to-payload cable during the free-fall phase.

3. Drag chute and cable weight effects are approximated by a concentrated weight at the chute attachment to the drop cable.

4. Weight and mass of the Trolley slide assembly are combined with the drop cargo weight.

5. Aerodynamic forces on cargo drop cables are neglected as vanishingly small compared to chute-generated drag loads and cable tension forces. However, aerodynamic forces on the cargo are important and were included in the analysis.

6. Elastic deformations of the drop cable are neglected in the cargo trajectory analysis.

The mathematical model was included in Appendix A of the Lockheed proposal.*

Preliminary investigations of various parameters affecting Trolley system performance were conducted in a manner such that gross boundaries of the acceptable values of these parameters could be established. Finer tuning of the system was accomplished later in the study with feedback from the flight test program and with results obtained from the analog simulation of the total system, including aircraft response. Therefore, the purpose of the initial analyses on the digital computer was to define better the permissible ranges of the various parameters affecting Trolley airdrop and to use these values as input starting points for the analog simulation. Table 1 shows the ranges of the various parameters investigated.

A trade-off between various parameters is possible in some cases; observations of the results of the digital computer analyses led to the following conclusions concerning the Trolley system and trade-offs. The value given after each parameter appears to be a "best" number as a result of preliminary digital investigations which used a C-130 flying at 110 knots and air dropping a 10,000-pound package.

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*Lockheed-Georgia Company. A Proposal for a Preliminary Investigation of the Trolley Low-Altitude Airdrop Concept, ETP 635. July 1965

Aircraft Velocity - Knots	110	130	150
Initial Cable Length - 100 feet	15 - 18	15 - 1[illegible]	15 - 19
Cable Length at Braking - 100 feet	18 - 23	18 - 22	18 - 23
Cable Tension at Winch after Initiation of Slip or Reel-in - g	1.0 - 1.8	1.0 - 1.8	1.0 - 1.8
Time at Initiation of Slip or Reel-in - seconds	7.0 - 8.0	7.0 - 8.0	7.0 - 8.0
Braking Time - Seconds	0.5 - 1.0	0.5 - 1.0	0.5 - 1.0
Slide Efficiency	0.95 - 0.98	0.98	0.95 - 0.98
Cable Tension During Free Fall at Winch - g	0.05 - 0.10	0.05 - 0.10	0.05 - 0.10
Thrust Increment	0 - 0.10	0 - 0.10	0 - 0.10
Extraction Acceleration - g	1.5 - 2.0	1.5	1.5

Table 1 – Range of Parameters Investigated

1. Initial Cable Length - 1500 Feet

   Short initial cable lengths result in higher horizontal velocities because the drop cargo does not have as long a path to expend horizontal velocity before it approaches the parachute. Longer initial cable lengths will result in lower horizontal velocities but at the expense of greater required drop altitude and more droop of the parachute below the airplane.

2. Cable Length at Braking - 1900 Feet

   Short cable lengths at braking result in the drag force of the parachute being applied to the drop cargo a shorter period of time and hence higher horizontal velocities occur. However, longer cable lengths at braking alleviate the horizontal velocity problem at the expense of higher vertical velocity and higher drop altitudes.

3. Cable Tension at Winch after Initiation of Reel-In - 1.8 g

   Low cable tension (about 1g) results in reeling out the winch instead of reeling-in and this prevents the drop cargo from sliding toward the parachute as rapidly. Hence, horizontal velocity is not dissipated as well. High cable tensions (about 2g) impose larger loads and greater power requirements on the winch. (Lower tensions usually require reel-out while the higher ones require reel-in for constant cable tension. A cable tension of about 1.8g generally results in moderate power requirements for the winch and produces the most acceptable impact velocities.)

4. Time at Initiation of Reel-In - 8.0 Seconds

   This is the time at which the winch reels cable in to maintain a constant line tension. The system seems relatively insensitive to this time within the range investigated. Outside the range shown in Table 1, however, the desirable characteristics obtained from reeling in are degraded.

5. Braking Time - 0.5 Seconds

   This is the time required to bring the winch to a complete stop after initiation of braking. Reasonable estimates for this time are on the order of 0.5 seconds.

6. Slide Efficiency - 0.95

This quantity is a function of the item of hardware that is ultimately used for the Trolley. It is estimated that it will be approximately 0.95.

7. Cable Tension at Winch during Free Fall - 0.05g

A small nominal tension is in the cable between the drop cargo and the winch during the time that the winch is free-wheeling. This value is estimated to be 0.05g.

8. Thrust Increment - (Zero)

Provisions have been made in the mathematical simulation of Trolley airdrop to allow the pilot to apply additional power at any time during the drop sequence. It is felt, however, that this is operationally undesirable and should be avoided if possible.

9. Extraction Acceleration - Highest Practical

It has been determined that extraction accelerations markedly affect results obtainable in Trolley airdrop. To date, the following three methods of extraction have been investigated:

- One-step 1.5g seems unacceptable because of 500-foot altitude restriction and power requirements for winch reel-in.
- Two-step 1.5g - 2.0g* lowers altitude, winch power requirements and horizontal impact velocity. Major problem here is power requirements for the winch.
- One-step 2.0g offers slightly improved performance over the above item.

It is emphasized that all of the above conclusions were based on a C-130 delivering a 10,000-pound payload. Further refinement and tuning of the system was accomplished during the latter stages of the mathematical investigations on the analog computer when various parameters such as

---

*By restraining the cargo with the winch, 1.5g net is applied to the drop cargo until it clears the airplane. After the cargo clears the airplane, the winch brake is released, thus increasing acceleration by 0.5g.

initial parachute position had been determined from flight test data. Therefore, all the values listed above are not necessarily the final recommended values. (See analog computer investigation section of this report.)

One particularly important factor was uncovered in these initial mathematical investigations that had not been particularly emphasized in previous studies of the problem: the initial parachute position in the trailing condition before extraction of the drop cargo plays an important role in the drop altitude required and the impact velocities of the drop cargo.

Figure [illegible] shows vertical velocity, horizontal velocity, and winch reel-in rate as a function of time for two different initial positions of the parachute below the airplane at initiation of the drop sequence. The solid curves result when the parachute is initially 30 feet below the airplane and the dotted curves result when the parachute is initially 90 feet below the airplane. Note that when the parachute is initially lower than some given reference position, the following conclusions can be drawn concerning the drop cargo:

1. Horizontal velocity is decreased.
2. Vertical velocity is increased.
3. Winch reel-in requirements are decreased.

It is obvious from these results that parachute position is very important to the Trolley airdrop.

Figure 3 shows the effect of changing the extraction acceleration. Vertical velocity, horizontal velocity, and winch reel-in rate are shown as functions of time for the three modes of extraction. The results of sequentially selecting extraction accelerations of one-step, 1.5g; two-step, 1.5g/2.0g; or one-step, 2.0g are as follows:

1. Vertical velocity gets progressively lower respectively and the slope of the curves near touch-down time is flatter, resulting in longer acceptable times for touch-down.

2. Horizontal velocity follows the same pattern as vertical velocity except that there is not as great a difference between the extraction modes - especially between the two-step, 1.5g/2.0g extraction and the one-step, 2.0g extraction.

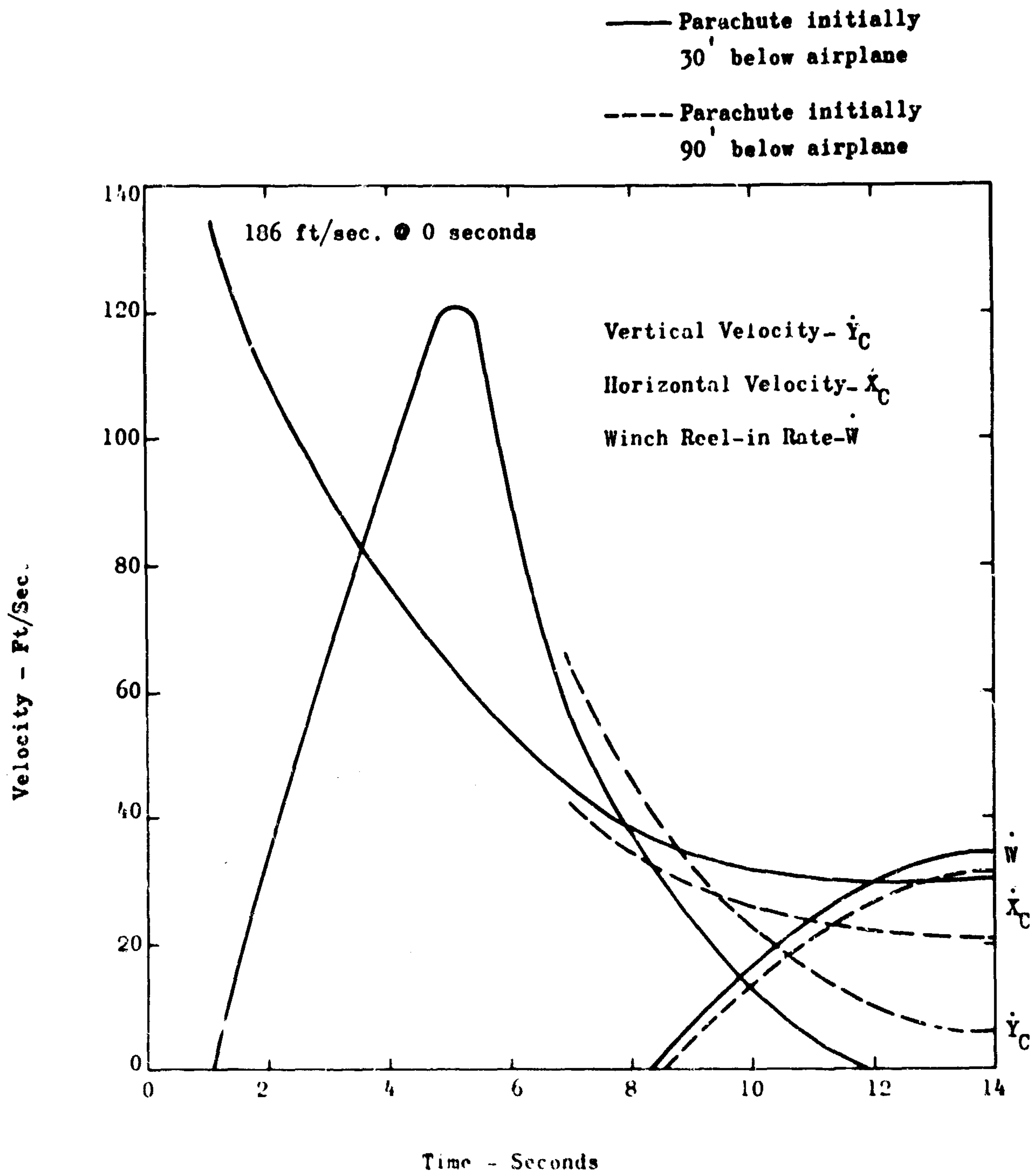


Figure 2 - Effect of Parachute Position

Altitude			
	One Step	1.5 g	611 Feet
	Two Step	1.5/2.0 g	522 Feet
	One Step	2.0 g	520 Feet

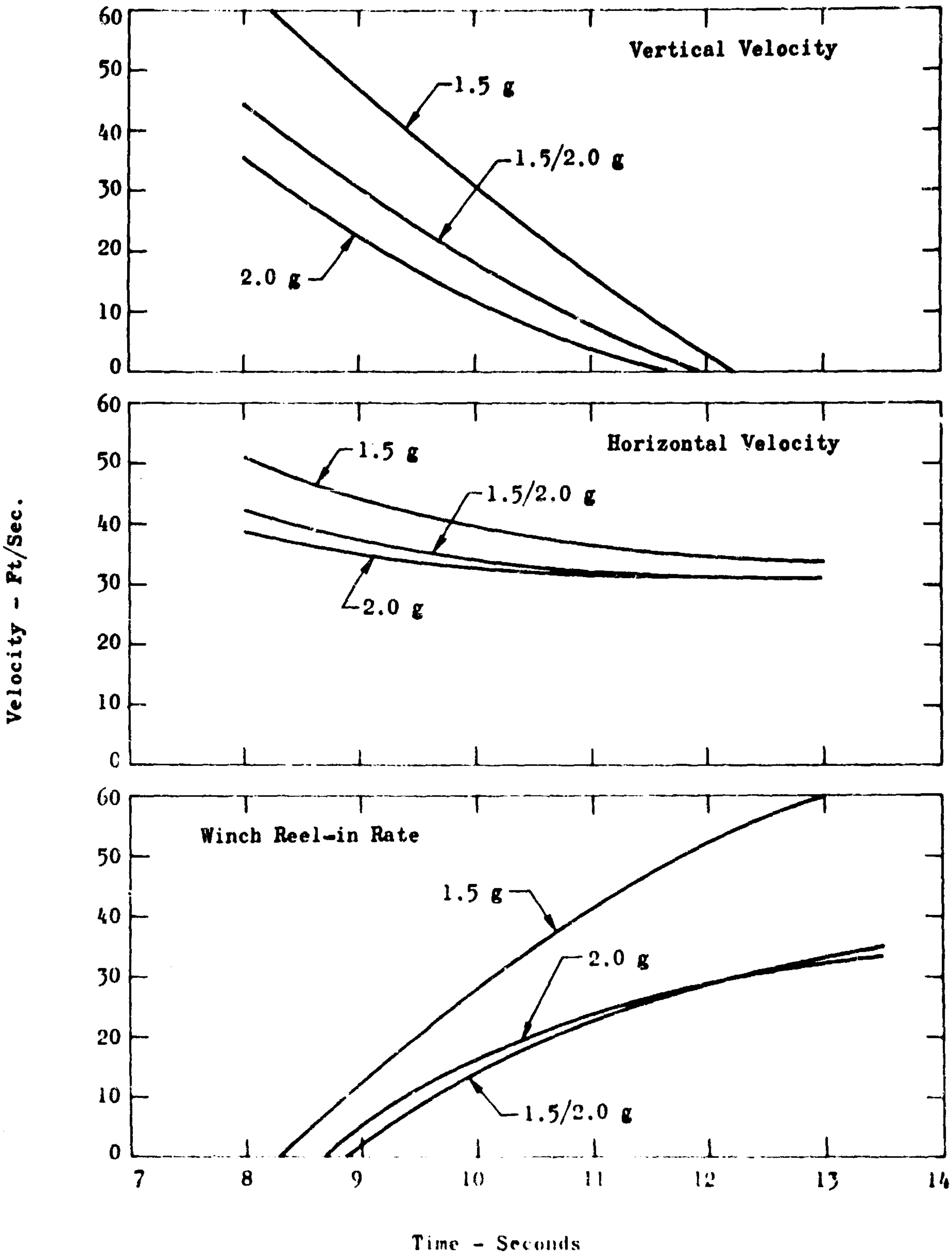


Figure 3 - Effect of Extraction Acceleration

3. Winch reel-in rate does not follow exactly the same pattern as horizontal and vertical velocity when the extraction mode is changed. The one-step, 1.5g extraction places very severe power requirements on the winch while the two-step, 1.5g/2.0g and the one-step 2.0g extraction are less demanding. Note that winch reel-in for the one-step, 2.0g extraction begins sooner than does the reel-in for the two-step, 1.5g/2.0g extraction. The reason for this is that in the one-step, 2.0g extraction the drop cargo leaves the airplane sooner and other events in the drop sequence naturally occur at a shorter time after initiation of the drop sequence. It should also be noted that the maximum power requirement for the winch is slightly greater for the two-step, 1.5g/2.0g extraction than it is for the one-step, 2.0g extraction.

A good visual indication of the altitude sensitivity of the system is the flatness of the velocity curves in Figures 2 and 3. The flatter the curve when close to touchdown time, the less sensitive the system is to altitude.

Since the data shown verify that the extraction acceleration does have a significant effect on Trolley capability, Lockheed requested that the Statement of Work of the subject contract be amended to allow investigation of higher extraction accelerations. At the suggestion of the Army Study Manager, this request was submitted to the U. S. Army Natick Laboratories for appropriate contractual action and approved; extraction accelerations of up to 3.0g were investigated later in the study.

A total of 91 digital computer runs were made by varying the parameters in Table 1 within the ranges shown in that figure. Digital computations were terminated at this point until results from the flight test portion of the study could be utilized to properly position the parachute. Another factor contributing to the temporary suspension of the digital investigation was the imminent results from the analog simulation which were expected to give more realistic results. In short, it was felt that the digital program had pointed the way or narrowed the range for the analog investigations. The digital program was used later in the study for the Sensitivity and Random Error and Accuracy analyses.

<u>Analog Computer Investigation</u>

The analog simulation of Trolley was constructed to simulate the total system operation including aircraft response. It was expedient to include flight dynamics and control of the airplane in this portion of the investigation rather than in Systems Analysis as presented in the Lockheed-Georgia Trolley proposal.

Derivation of Equations - The approach taken in the analysis of this problem was to derive the equations of motion for the airplane, cargo, and parachute when each was considered as a separate body connected only by the tension in the trailing cable. Figure 4 shows the axes systems used in this analysis. Positive directions of the axis system from the center of gravity are as follows: Forward - plus X, downward - plus Z, and nose-up pitching moment - plus M.

Using the symbols shown in the Glossary summing forces along the X axis,

$$\Sigma F_X = m\dot{U}$$

Expanding into aerodynamic terms yields

$$\Sigma F_X = T \cos \alpha - W_a \sin \gamma - D,\ F(\alpha) + F_{\bar{X}}$$

where

$$F_{\bar{X}} = F_p \sin \alpha + (T_{R_X} - T_{D_X}) \cos \alpha$$

Rewriting the equation and making the appropriate substitutions yields,

$$m\dot{U} = T \cos \alpha - W_a \sin \gamma - D,$$
$$f(\alpha) + F_p \sin \alpha + (T_{R_X} - T_{D_X}) \cos \alpha \tag{1}$$

Summing forces along the Z axis yields,

$$\Sigma F_Z = - mU\dot{\gamma}$$

The expansion of this equation into aerodynamic terms yields,

$$\Sigma F_Z = - T \sin \alpha + W_a \cos \gamma - L,\ f(\alpha, \delta_e) + F_{\bar{Z}}$$

where

$$F_{\bar{Z}} = F_P \cos \alpha + (T_{D_Z} + T_{R_Z}) \sin \alpha$$

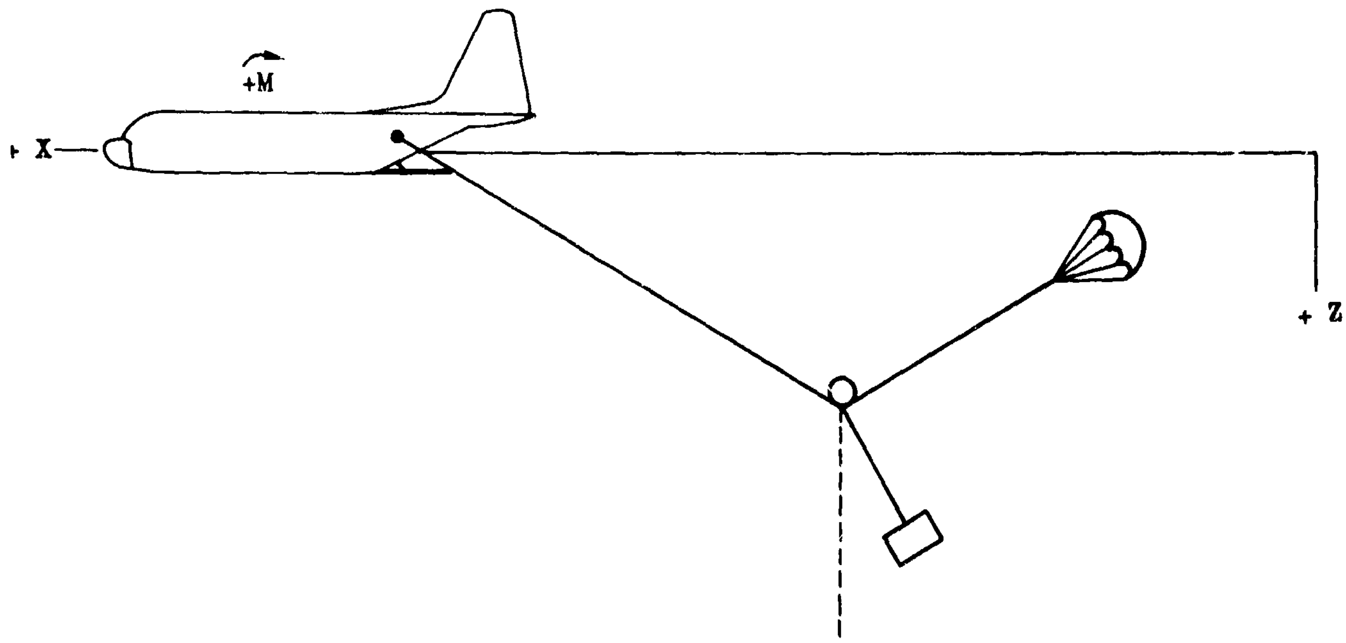


Figure 4 – Axes System Used for Mathematical
Modeling of the Trolley System

Rewriting the equation and making the appropriate substitutions yields,

$$- m_a U \dot{\gamma} = - T \sin\alpha + W_a \cos\gamma - L, f(\alpha, \delta_e) + F_P \cos\alpha + (T_{D_Z} + T_{R_Z}) \sin\alpha \qquad (2)$$

Summing moments about the center of gravity in the X-Z symmetrical plane through which passes the Y axis perpendicular to this plane yields,

$$\Sigma M_{c.g.} = I \ddot{\theta}$$

Expanding into aerodynamic terms yields,

$$\Sigma M_{c.g.} = M_{a.c.}, f(\alpha) + M_{\dot{\theta}} \dot{\theta} + M_{\dot{\alpha}} \dot{\alpha} + M_{\delta_e} \delta_e + M_{\overline{c.g.}}$$

where

$$M_{\overline{c.g.}} = F_P x_c + T_{D_X} z_1 + T_{D_Z} x_1 + T_{R_Z} x_2 + T_{R_X} z_2$$

Rewriting the equation and making the appropriate substitutions yeilds,

$$I \ddot{\theta} = M_{a.c.}, f(\alpha) + M_{\dot{\theta}} \dot{\theta} + M_{\dot{\alpha}} \dot{\alpha} + M_{\delta_e} \delta_e + F_P x_c + T_{D_X} z_1 + T_{D_Z} x_1 + T_{R_X} z_2 + T_{R_Z} x_2 \qquad (3)$$

where

$$I = I_a + I_c + m_c x_c^2$$

These three equations are presented in a manner necessary to achieve the flexibility needed to study systems that have not been solidified by design hardware. Additional terms may be easily added depending upon the nature of the system under consideration.

It is appropriate at this point to write the equation that simulates the cargo floor load due to both cargo weight and aft movement of this

weight. This equation is given as the summation of loads that cause changes in the cargo floor forces and is written in accordance with Figure 5, thus:

$$F_P = W_c \cos \theta + m_c U \dot{\gamma} \cos \alpha - m_c \dot{\theta} \dot{x}_c - m_c x_c \ddot{\theta}$$

This equation accounts for the Coriolis effect caused primarily by the aft movement of the cargo and has been found to be significant in previous Lockheed studies.

The cargo equations of motion were derived in the same manner as those of the airplane; i.e., summing forces and moments about a point. In this situation the forces and moments were summed about the pulley.

Figure 7 shows the coordinate system of the cargo. Summing forces in the X direction yields,

$$\Sigma F_X = T_\omega \cos \omega - T_\beta \cos \beta - F_D - F_c \sin \phi = m_c \ddot{x}_c$$

where

$$F_D = C_{D_c} \, 1/2 \, \rho U_c^2 S_\pi$$

$$F_D = 1/2 \, C_{D_c} \rho S_\pi \left(\frac{\dot{X}_c}{U}\right)^2 = k x_c^2$$

$$F_c = W_c \cos \phi, \text{ and}$$

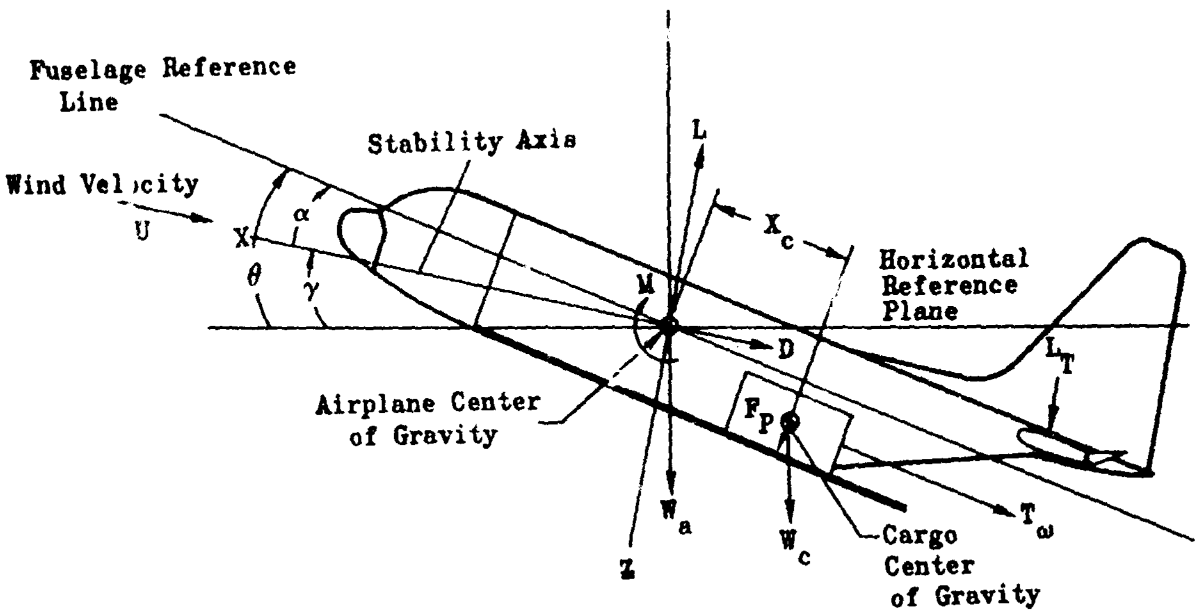
$$T_\beta = \eta T_\omega$$

Rewriting the equation and making the appropriate substitutions yeilds:

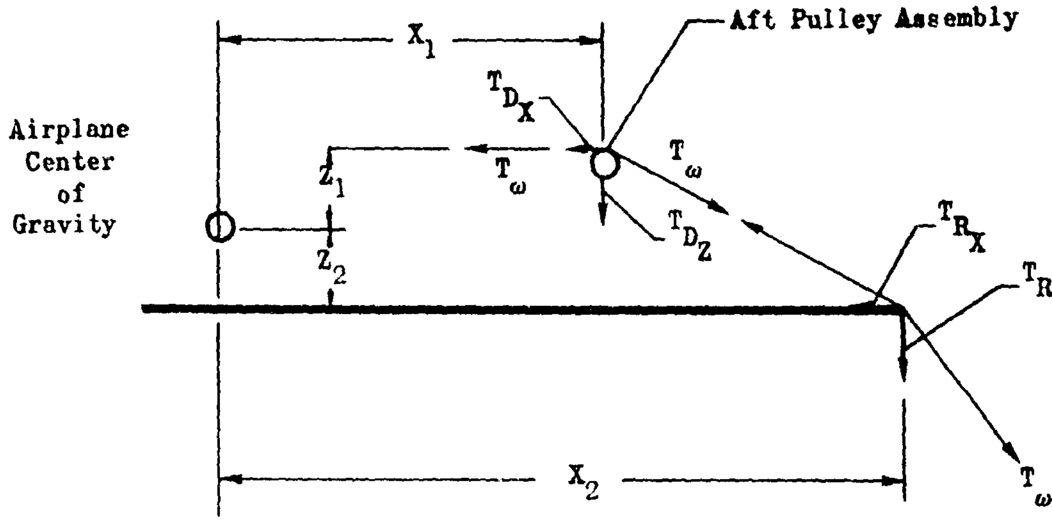
$$m_c \ddot{x}_c = T_\omega (\cos \omega - \eta \cos \beta) - k x_c^2 - F_c \sin \phi$$

Summing forces in the Z direction yields,

$$-m_c \dot{Z}_c = - T_\omega (\sin \omega + \eta \sin \beta) + F_c \cos \phi$$



Before Extraction



After Extraction

Figure 5 – Stability Axis System and Resultant Cable Forces

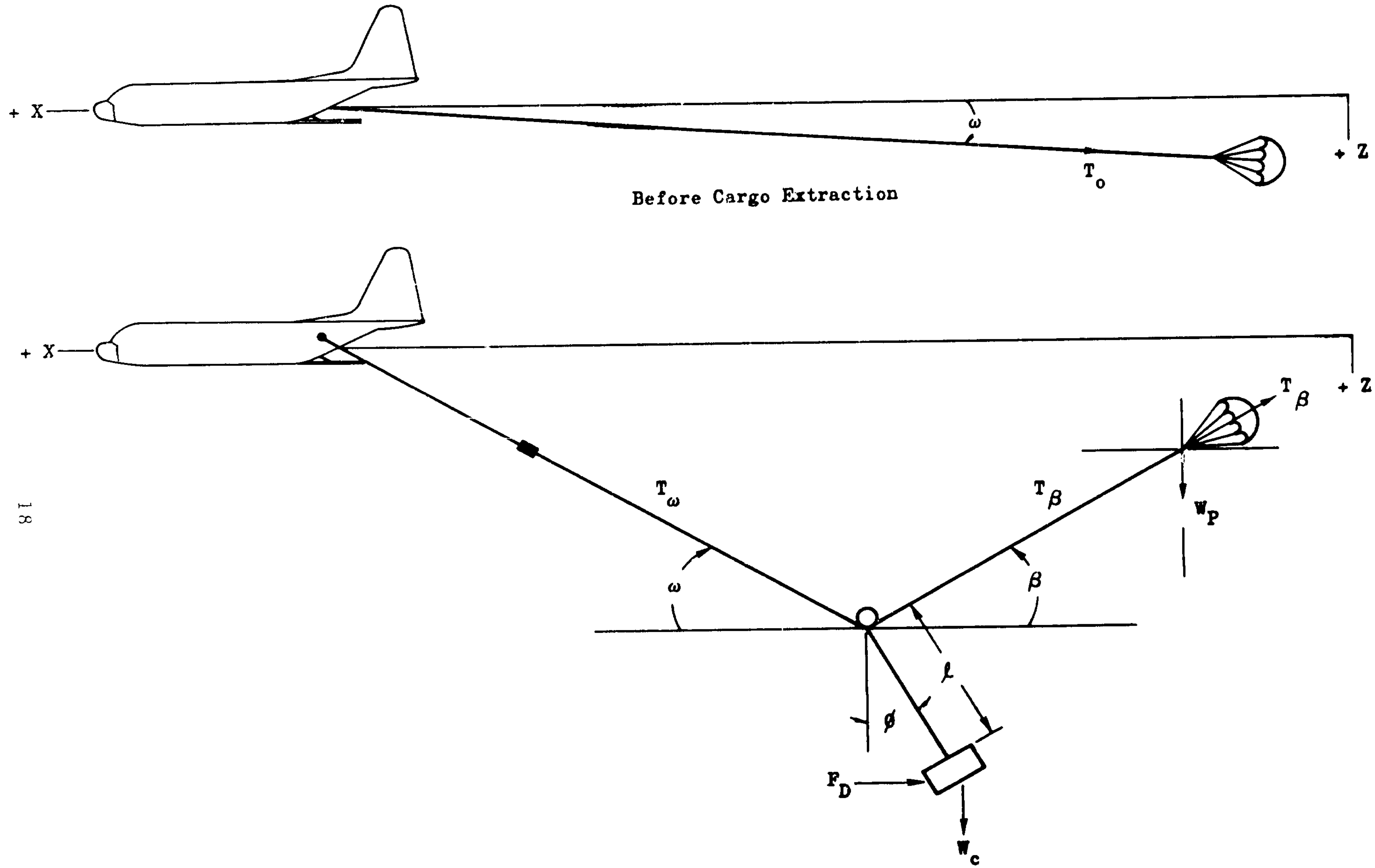


Figure 6 - Coordinate System after Cargo Extraction

The schematic drawing of Figure 6 shows that the cargo possesses the effects of a pendulum. The equation of motion that describes this effect is derived by summing moments about the slide. Therefore

$$W_c\ (\ell \sin \phi) - F_D\ (\ell \cos \phi) = I_c\ \ddot{\phi}$$

Rewriting the equation and making the appropriate substitutions with the symbolism of the ΣF_X equation yields:

$$I_c\ \ddot{\phi} = (W_c \sin \phi - k\ \dot{x}_c \cos \phi)$$

Parachute equations are obtained by summing forces in the X and Z directions.

$$\Sigma F_X = -\ T_\beta \cos \beta = m_p\ \ddot{x}_p$$

$$\Sigma F_Z = W_p - T_\beta \sin \beta = -\ m_c\ \ddot{Z}_c$$

The equations of motion as presented above describe the response of each of the three coordinate systems employed. Auxiliary equations are needed to describe the phenomena associated with airdrop that are not present in standard flight of the airplane. These equations are listed and discussed below.

o <u>Tip-Off Phenomenon</u> - The tip-off phenomenon is described as the mathematical representation of a decrease in cargo floor load as the last half of the airdrop package passes the ramp door lip. The cargo package is considered to be a point mass acting at its own center of gravity. The rearward travel of this mass causes nose-up pitching moments about the airplane center of gravity. Theoretically, when this point mass reaches the lip, the pitching moment becomes zero. This theory, however, is not the true representation of the physical system. Consider the system shown in Figure 7.

  The cargo at rest is shown by the dashed block. Pitching moment build-up caused by the aft movement of the cargo reaches a peak as the cargo center of gravity passes the lip. The floor load is assumed to be relieved linearly by the rate of cargo density. For example, if the package weighs 10,000 pounds and has a density of 833 pounds per foot of length, then the relieving load will become

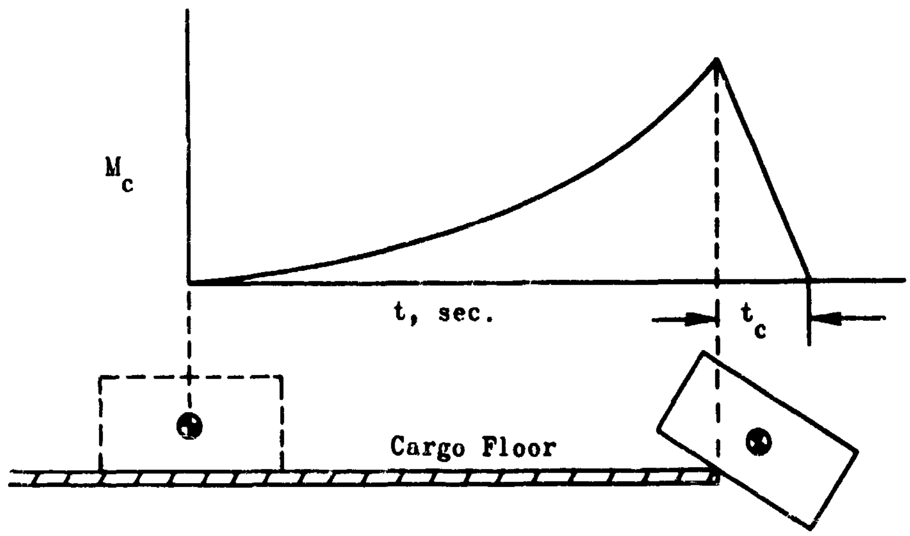


Figure 7 - Tip-Off Phenomenon

zero at six feet after the cargo center of gravity passes the lip. The accelerating cargo is shown in the tipped position along with a representation of the corresponding input pitching moment. M_c is calculated by

$$M_c = F_P \cdot x_c \text{ and } x_c = 1/2\, \ddot{x}_c\, t^2$$

o <u>Cargo Extraction Acceleration</u> - The distance that the cargo travels in the airplane in a given amount of time depends directly upon its acceleration. The cargo location in the airplane is computed simply by

$$x_c = 1/2\, \ddot{x}_c\, t^2$$

where

x_c = distance cargo center of gravity travels in airplane, feet,

$\ddot{x}_c$ = cargo acceleration, feet per second squared, and

t = time, seconds

In this analysis the cargo acceleration, $\ddot{X}_c$, is given a value of 32.2 feet per second squared unless otherwise stated. This parameter is non-dimensionalized by the cargo weight, i.e., for a 2g extraction, the extraction force applied is twice the cargo weight.

- <u>Extraction Cable Tension</u> - The extraction cable tension is generated as a function of line length and size of parachute being towed. The equation that computes the tension in the cable before the cargo is released is given by,

$$T_\beta = K\left[\frac{L_2}{L_0} - 1\right]$$

where

T_β = line tension between the cargo and parachute, pounds,

K = force produced by the parachute, pounds,

L_0 = initial unstretched line length, feet,

L_2 = stretched line length between the cargo, and parachute

The cable tension between the cargo and winch during the free-fall phase is computed as follows:

$$T_\omega = T_1 = \frac{\xi r - L_1}{\xi r}$$

where

L_1 = stretched line length between the cargo and winch,

r = distance from winch drum center to outside of pay-out cable, feet

ξ = the number times the winch drum rotates, radians,

T_ω = cable tension between cargo and winch drum, pounds, and

T_1 = initial cable tension, pounds

The cable tension generated after the winch brakes are applied is given as,

$$T_\beta = K\left[\frac{(L_1 + L_2) - (L_o + \xi r)}{(L_o + \xi r)}\right]$$

where

$(L_1 + L_2)$ = total stretched line length, and

$(L_o + \xi r)$ = total unstretched line length

The other symbols in this equation have been previously defined.

o <u>Winch Drum Equation</u> - The equation of motion that represents the rotational characteristics of the winch drum is given by

$$I_\omega \ddot{\xi} = \left[T_\omega - T_{\omega_{SET}} \left\langle \begin{matrix} t = 8.0 \\ @\ 1.8\ g's \end{matrix} \right\rangle - T_{FRICTION}\right] r$$

where

I_ω = winch drum and cable inertia,

$T_{\omega_{SET}}$ $\begin{matrix} t = 8.0 \\ @\ 1.8\ g's \end{matrix}$ = the cable tension limited to 1.8 times the cargo weight at the end of 8.0 seconds after cargo release, and

$T_{FRICTION}$ = cable tension caused by winch drum bearing friction.

The analog wiring diagrams for the equations derived above appear in Appendix I.

Parametric Analysis - A parametric analysis of the Trolley concept was made on the analog computer using the simulation derived above. Results from the preliminary digital investigation were used as guidelines for the initial analog work. The primary purpose was to seek an optimum combination of cargo horizontal impact velocity, vertical impact velocity, and airdrop altitude. Ground rules were established which limited the initial drop altitude to a maximum of 500 feet and a maximum vertical velocity of 28.5 feet per second. No upper limit was specified in the Work Statement on the horizontal velocity, but in the process of optimization, attempts were made to keep it as low as possible. The approach was to select a set of basic parameters and to vary them over a practical range one at a time. Initial selection of these data was based on digital computer results obtained early in the study. The simulation utilized a C-130 aircraft flying at 130 knots at sea level on a standard day. The drop cargo weight was 10,000 pounds.

This parametric analysis consisted of 77 analog computer runs, each consisting of 24 variables recorded as time histories and four recorded on the X-Y plotter. From these data the cargo horizontal and vertical velocities and drop altitude were read and plotted versus the parameter being investigated. These static plots led to the selection of values for each parameter that permitted optimization of the system.

The following parameters were investigated to determine their effects on cargo horizontal velocity, cargo vertical velocity, and drop altitude:

1. Time to brake winch
2. Cable depression angle
3. Cargo aerodynamic drag
4. Slide efficiency
5. Initial cable length
6. Time at initiation of winch reel-in
7. Payout before braking
8. Cable tension

- Time to Brake Winch - One phase of the Trolley system is that of braking the winch to a complete stop after the cargo free-fall. The time span required to stop the winch drum has an effect on the touchdown parameters. This braking time span was varied from 0.1 through 2.0 seconds and the results are shown in Figure 9. An increase in braking time decreases the cargo horizontal velocity and increases drop altitude. It is interesting to note that the horizontal velocity and drop altitude were read from the time histories at the instant the vertical velocity became zero; hence drop times are not identical but the total time for the drop sequence varies only slightly.

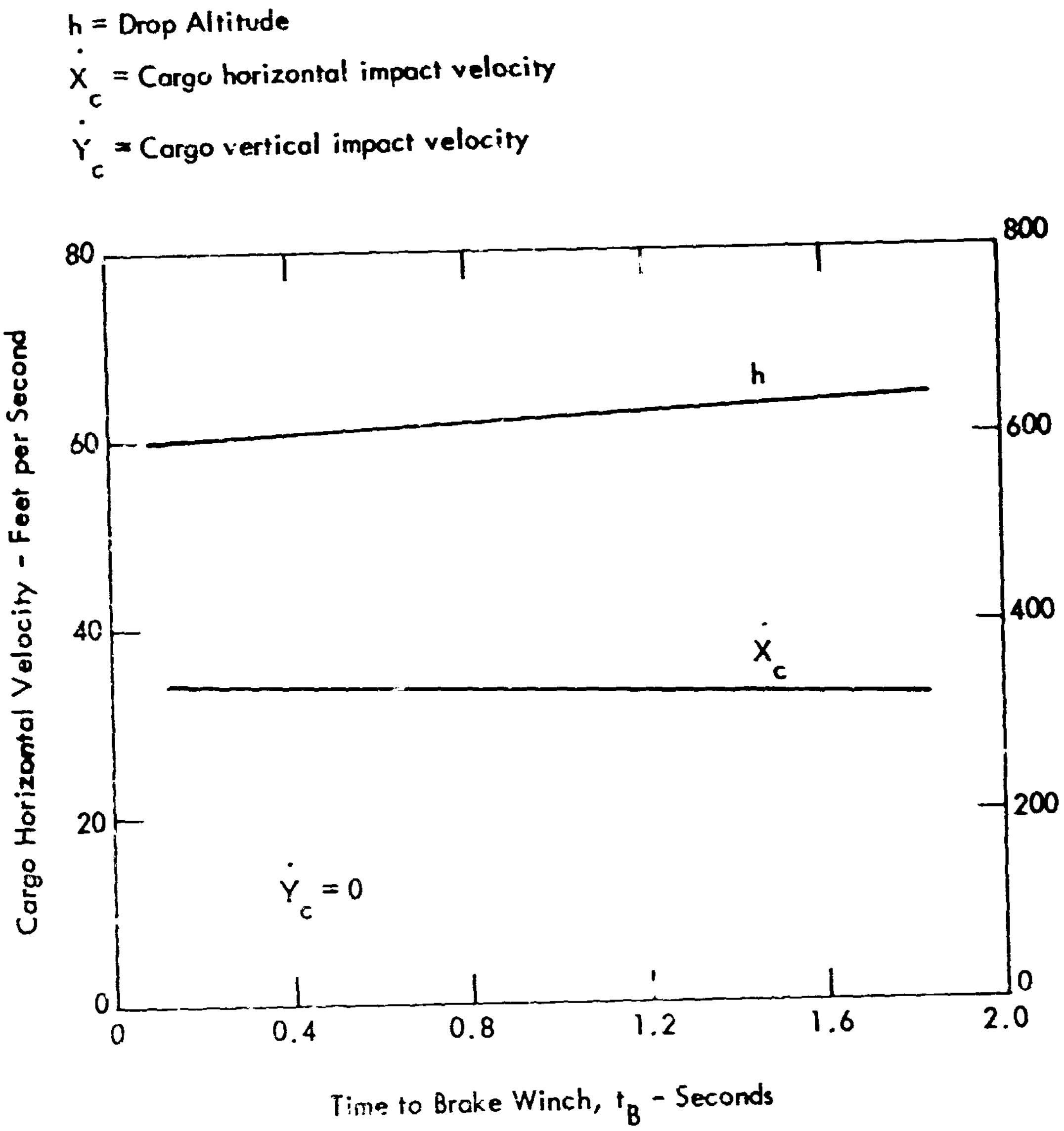


Figure 4 - Parametric Analysis - Time to Brake Winch

- <u>Cable Depression Angle</u> - The parachute trails below the airplane as it is towed because of the weight of the cable and the parachute. The angle created by a straight line from the parachute to the airplane and the horizontal reference line is defined as the cable depression angle. In the process of determining this angle, a simple mathematical method already programmed on the digital computer was used as a beginning point. From this point the angle was altered throughout a practical range of values. A large angle increases the drop altitude significantly because the parachute does not arrest vertical velocity as well in this position. For this reason the most significant limit on the maximum value was how far below the airplane the parachute trailed. For example, if the initial cable length is 1300 feet and it is trailing at an angle of 4 degrees, the parachute is depressed a distance equal to 1300 feet times the sine of 4 degrees (91 feet) below the airplane. Under the same conditions the parachute is 182 feet below at an 8-degree angle. For a 1500-foot cable and a 4-degree depression angle, the parachute trails 105 feet below the airplane and approximately twice that distance when trailing at 8 degrees. Figure 9 shows the variation of cargo horizontal velocity, cargo vertical velocity, and altitude as a function of cable depression angle. The cargo horizontal velocity decreases at a rate of about 1.6 feet per second for each degree of increase of cable depression angle while cargo vertical velocity and altitude remain essentially unchanged.

  The mathematical analysis of the shape of the towed cable produced an angle of approximately 4 degrees under the prescribed flight conditions. When this result was combined with the flight test data obtained later in the program, a value of about 5 degrees was determined to be more representative. Flight test results are discussed later in this report.

- <u>Cargo Aerodynamic Drag</u> - One of the tasks in this study was to determine the effects of aerodynamic drag on the airdrop cargo. This force helps retard the cargo horizontal velocity but also increases the period of the cargo "swing" which might place it in such a position that damage may occur at touchdown or it may contribute to tumbling of the cargo. It was assumed that the aerodynamic force was proportional to the square of the velocity. Figure 10 shows the results with cargo horizontal velocity, cargo vertical velocity, and drop altitude plotted versus the aerodynamic drag factor, K. It is seen that the horizontal velocity of the cargo decreases slightly with increasing aerodynamic drag while cargo vertical velocity and drop altitude

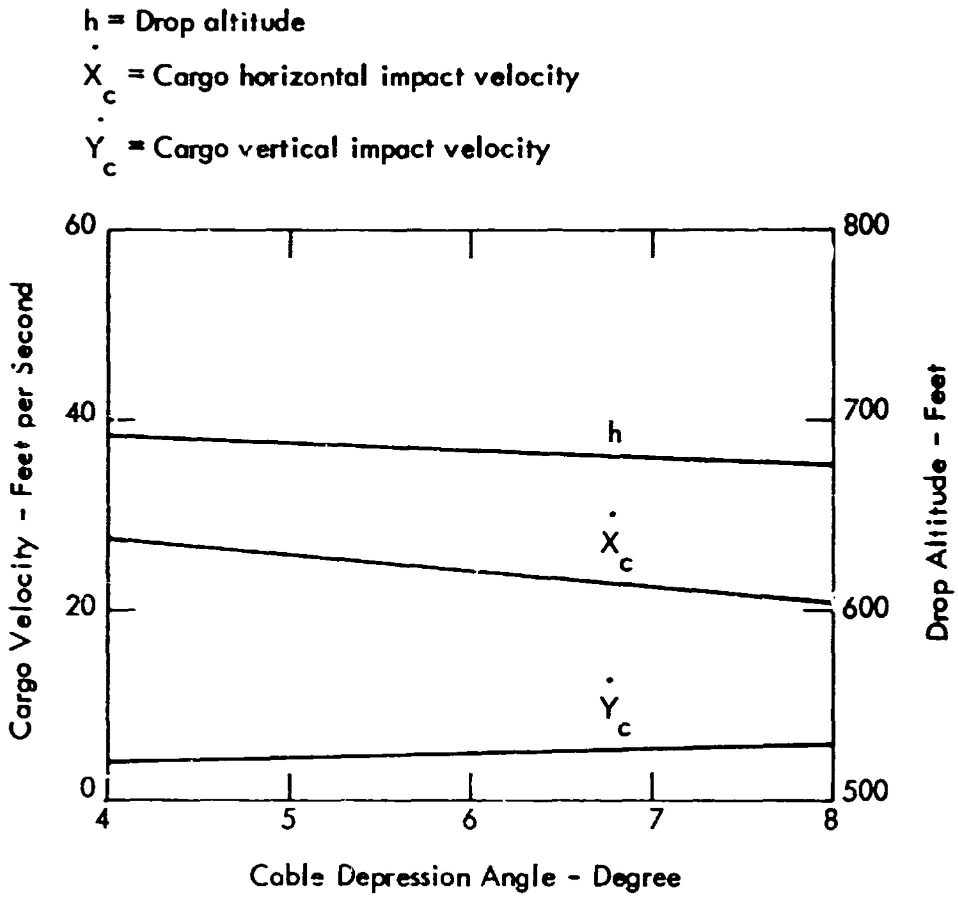


Figure - Parametric Analysis - Cable Depression Angle

Cargo Aerodynamic Drag = $K \left(\frac{\text{drop cargo velocity}}{\text{aircraft velocity}}\right)^2$

h = Drop altitude

$\dot{X}_c$ = Cargo horizontal impact velocity

$\dot{Y}_c$ = Cargo vertical impact velocity

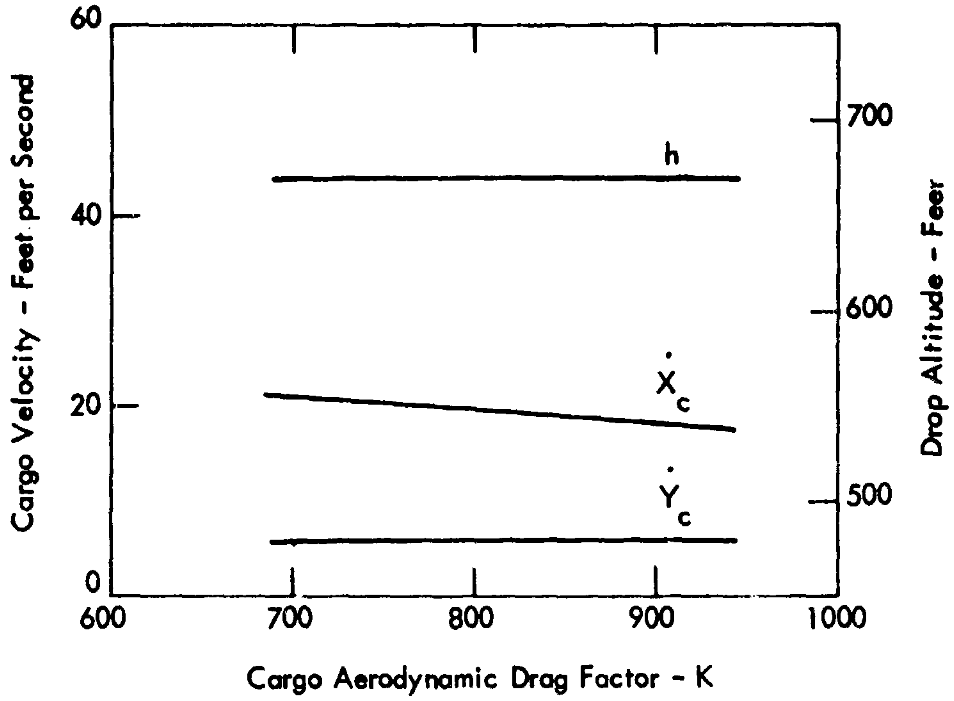


Figure 10 - Parametric Analysis - Cargo Aerodynamic Drag Factor

remain relatively unchanged. Since none of these parameters are very sensitive to aerodynamic drag in this range of values, a value of 700 for the aerodynamic drag factor was selected as representative.

- Slide Efficiency - A study of friction between the slide and cable was conducted to determine its effect on system performance since increased friction decreases slide efficiency as it passes along the cable. Figure 11 shows the variation of cargo horizontal velocity, cargo vertical velocity, and drop altitude as slide efficiency is increased (friction decreased); the higher the slide efficiency the lower the vertical velocity and drop altitude while cargo horizontal velocity remains essentially unchanged. It was determined that a slide mechanism for Trolley airdrop could be manufactured with an efficiency of about 0.95. Thus, this value was used in all further analyses.

- Initial Cable Length - Figure [illegible] shows a plot of the variation of cargo horizontal velocity, cargo vertical velocity, and drop altitude versus the length of the cable towing the parachute just prior to extraction. Increasing the initial cable length decreases both cargo horizontal velocity and cargo vertical velocity significantly, but the drastic increase in drop altitude becomes prohibitive. The cargo horizontal velocity decreases at a rate of about 3.4 feet per second per 100 feet of increase in initial cable length while the vertical velocity decreases at a rate of about 2.3 feet per second, and the drop altitude increases about 45 feet. A compromise must be made here in order to obtain a satisfactory drop altitude. It was necessary that drop altitude be held below 500 feet since it is a requirement of the contract Work Statement. Hence, values were chosen so that the altitude would be satisfactory.

- Time at Initiation of Reel-In - Figure 13 shows the effects of the time at initiation of reel-in on cargo horizontal velocity, cargo vertical velocity, and drop altitude. After extraction of the cargo and the free-fall phase, the winch is braked; the time (measured from beginning of extraction) at which this braking action occurs, affects the cargo velocities and altitude. For the parameters shown on the figure, it is seen that a time of about 8 seconds results in the best compromise. However, the Trolley system does not appear to be very sensitive to the time that reel-in is initiated.

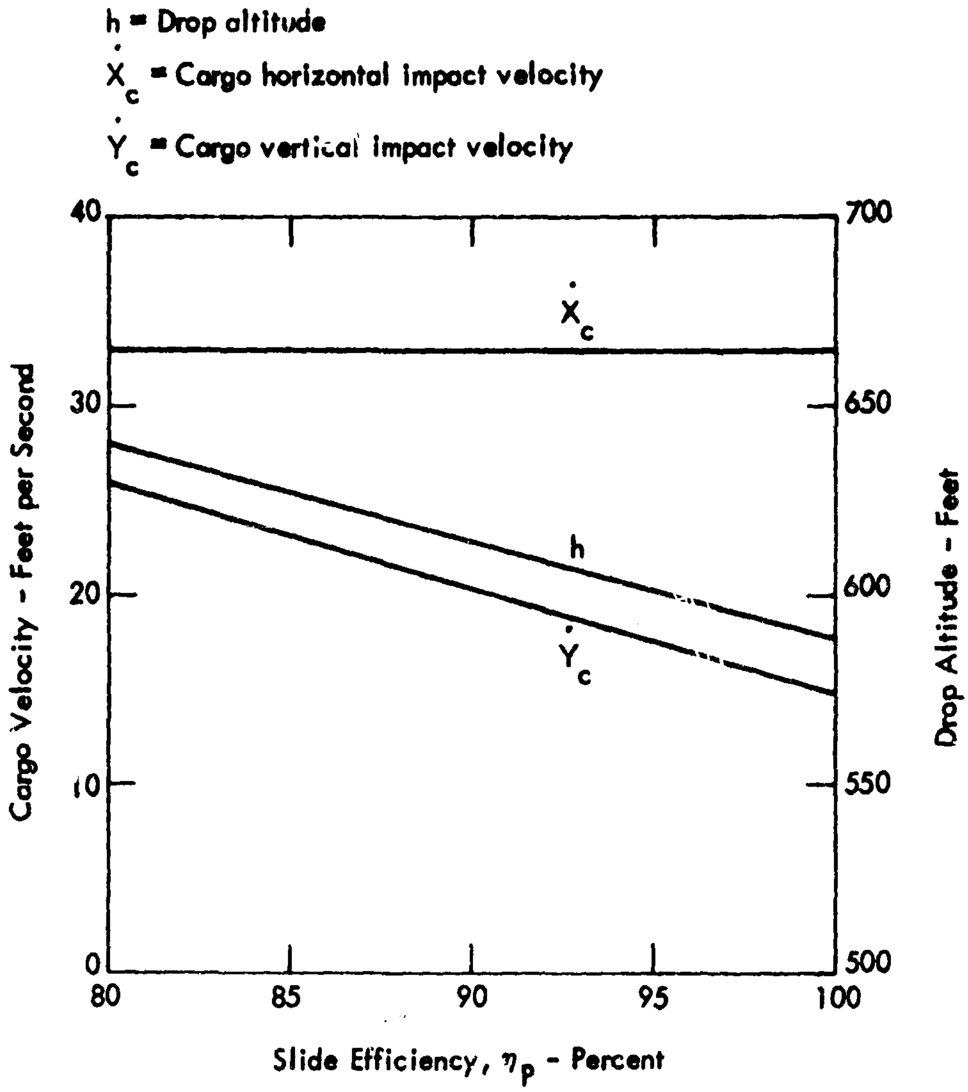


Figure 11 - Parametric Analysis - Slide Efficiency

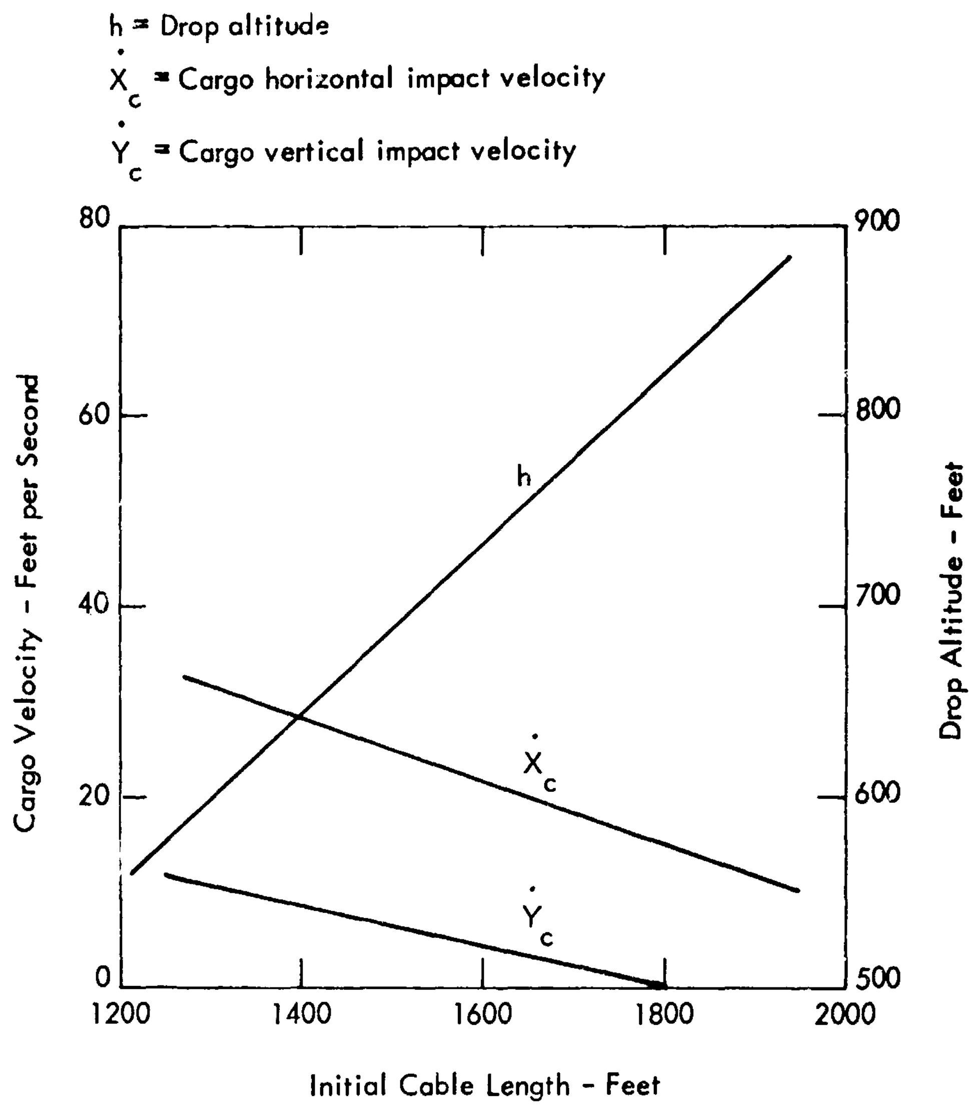


Figure ; . - Parametric Analysis - Initial C.ble Length

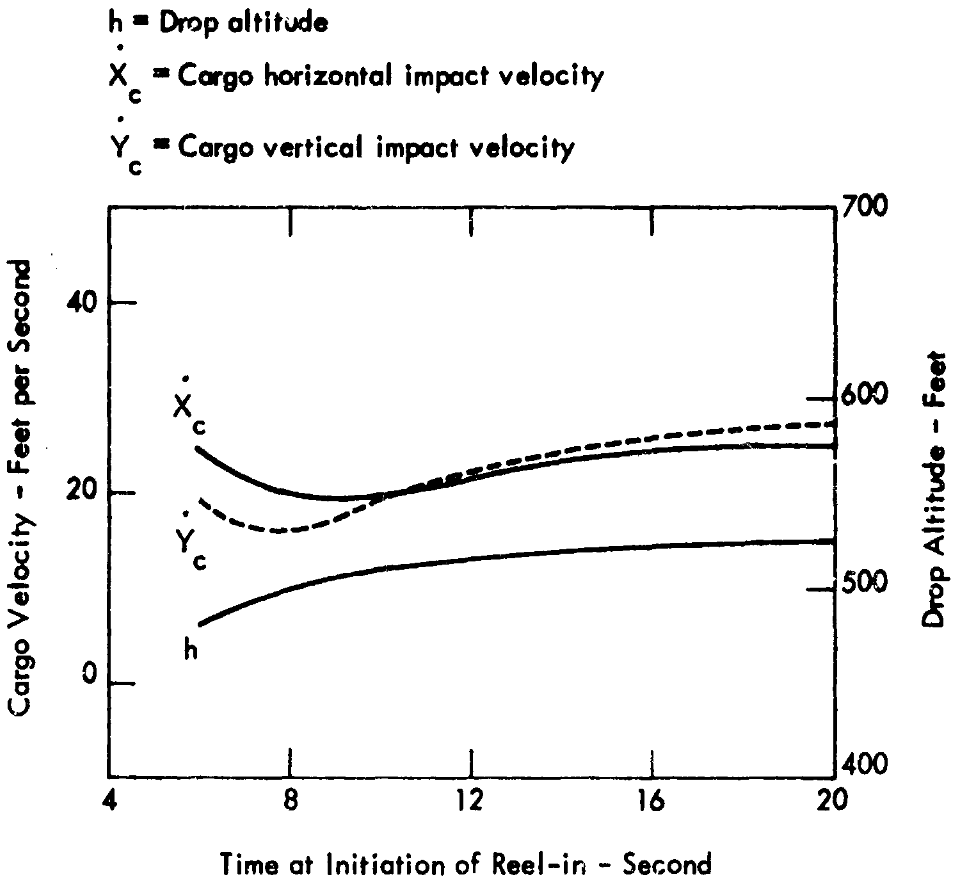


Figure 13- Parametric Analysis - Time of Initiation of Reel-in

- Payout Before Braking - This parameter is defined as the length of line that leaves the winch drum from the beginning of extraction to the braking of the winch. From Figure 14 it is seen that the dependent quantities of concern are markedly affected by this parameter. Short payout lengths result in lower drop altitudes, but increased horizontal and vertical impact velocities result. A tradeoff is in order here because the magnitudes of the velocities associated with a short payout length are still within the ground rules established for this study, and even lower drop altitudes result. Therefore, 350 feet of payout was selected so that drop altitude could be held under 500 feet for the initial cable length of 1300 feet.

- Cable Tension During Reel-In - After the free-fall phase and braking of the winch, the trolley and cargo begin a rearward movement relative to the cable toward the parachute. During this movement, the winch automatically adjusts itself to maintain a constant cable tension; to do this, the winch is required to reel-in. Figure 15 shows the effects of varying the value of this constant cable tension on the impact velocities and drop altitude.

Analog Results

As a result of the parametric study on the analog computer, the following values were selected as optimum within the constraints of the Work Statement:

- Time to brake winch = 0.5 seconds*
- Cargo aerodynamic drag factor = 700
- Cable depression angle = 5 degrees
- Time at initiation of winch reel-in = 8 seconds
- Initial cable length = 1300 feet
- Slide efficiency = 95 percent
- Payout before braking = 350 feet
- Cable tension during reel-in = 1.8 g's

All of these values were selected so that the 500-foot maximum airdrop altitude would not be exceeded. Vertical and horizontal impact velocities assumed secondary importance to airdrop altitude, but they were

*Due to dynamic loads imposed on the cable, this value was increased to 1.5 seconds. The sensitivity analysis shows effects of changing this variable and the results indicate that no problems will arise from this change.

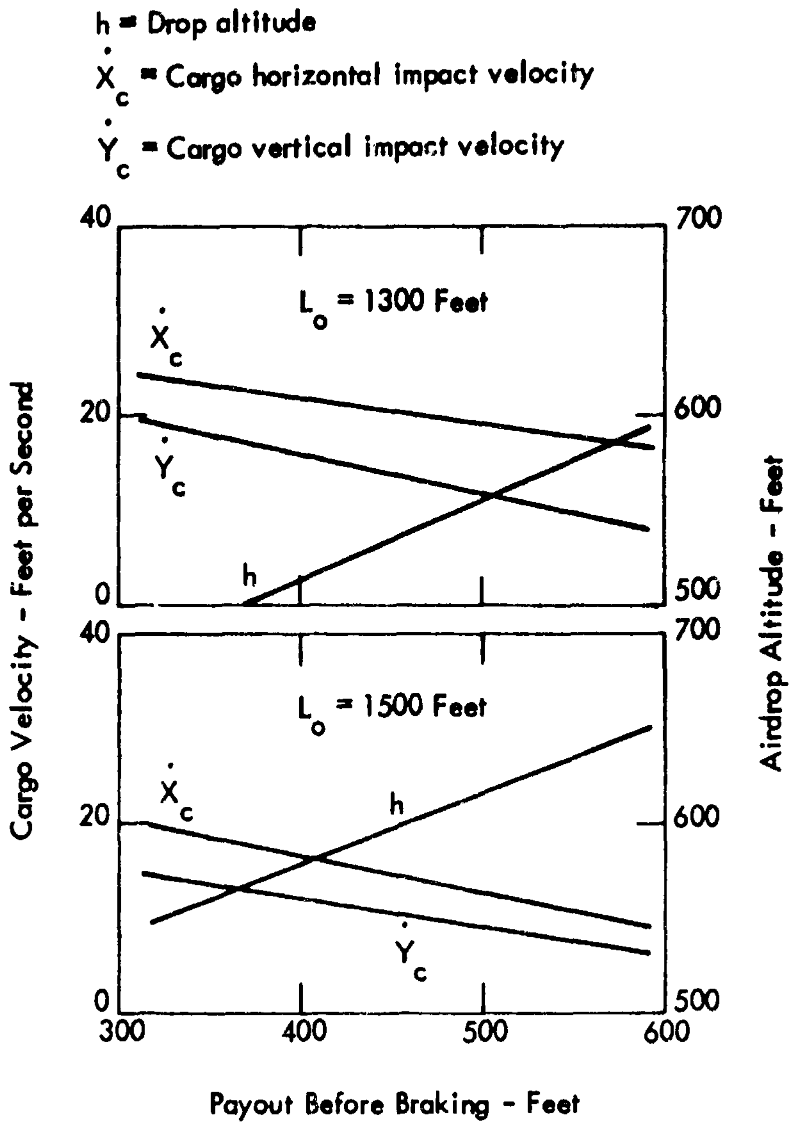


Figure 14 - Parametric Analysis - Payout Before Braking

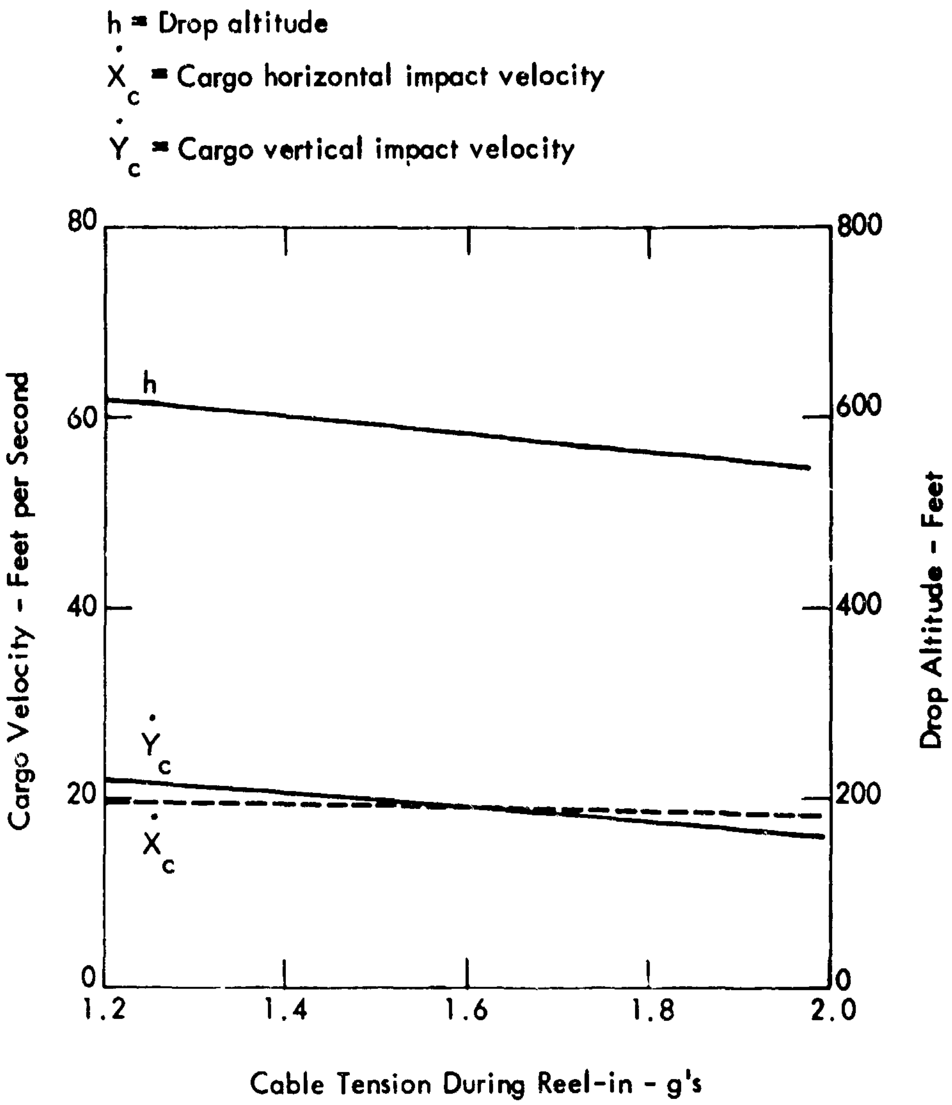


Figure - Parametric Analysis - Cable Tension During Reel-in

minimized subject to this drop altitude constraint. The selection of the above values was also compromised so that Trolley could operate over the airdrop speed range of 110-150 knots as specified in the Work Statement.

By taking the optimum values of the drop parameters listed above and applying them to specific operational conditions, the actual capabilities of Trolley were determined. The operating conditions considered were as follows:

- o Airspeed = 110, 130, 150 knots
- o Cargo weights = 2000, 6000, 10,000 pounds
- o Cargo extraction accelerations = 1.5, 2.0, 3.0 g's
- o Winch reel-in rates = 10, 20, 30 feet per second

Forty-five analog computer runs were made using various combinations of these conditions and using the eight inputs listed earlier. The following table shows the combinations used for the parametric study and the figures which present the final analog results of Trolley capability.

	Aircraft Speed Range - Knots	Cargo Weight - Pounds	Extraction Acceleration - g	Reel-In Rate - fps
o Figure 16	110 - 150	2000, 6000, 10,000	1.5	30
o Figure 17	110 - 150	2000, 6000, 10,000	2.0	30
o Figure 18	110 - 150	2000, 6000, 10,000	3.0	30
o Figure 19	110 - 150	2000, 6000, 10,000	2.0	10
o Figure 20	110 - 150	2000, 6000, 10,000	2.0	20

Figures 16 - 18 show that increasing extraction acceleration reduces the values of horizontal and vertical impact velocities and drop altitude.

Figures 16 - 20 show that Trolley is excellent in arresting vertical impact velocity but that horizontal velocity can be troublesome. Horizontal impact velocity increases rapidly as drop speed increases. Thus, drop speed should be minimized. On the other hand, drop altitude is almost insensitive to changes in aircraft speed.

Figures 16 - 20 also show the effect of changes in drop weight. Drop altitude and vertical impact velocity decrease as drop weight increases; however, horizontal impact velocity increases.

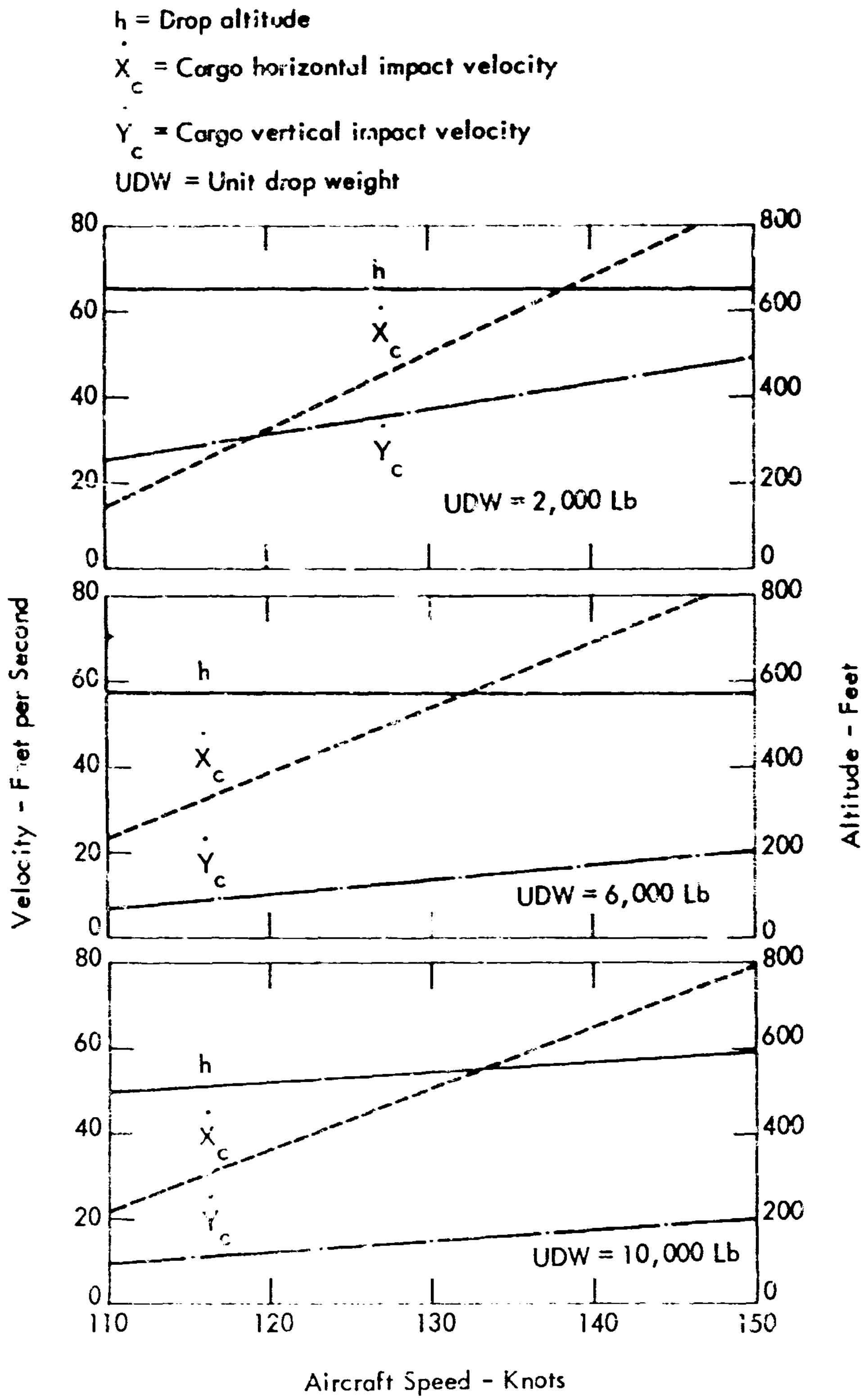


Figure - Analog Results - 1.5 g Extraction Acceleration with 30 Feet per Second Winch Reel-in

h = Drop altitude

$\dot{X}_c$ = Cargo horizontal impact velocity

$\dot{Y}_c$ = Cargo vertical impact velocity

UDW = Unit drop weight

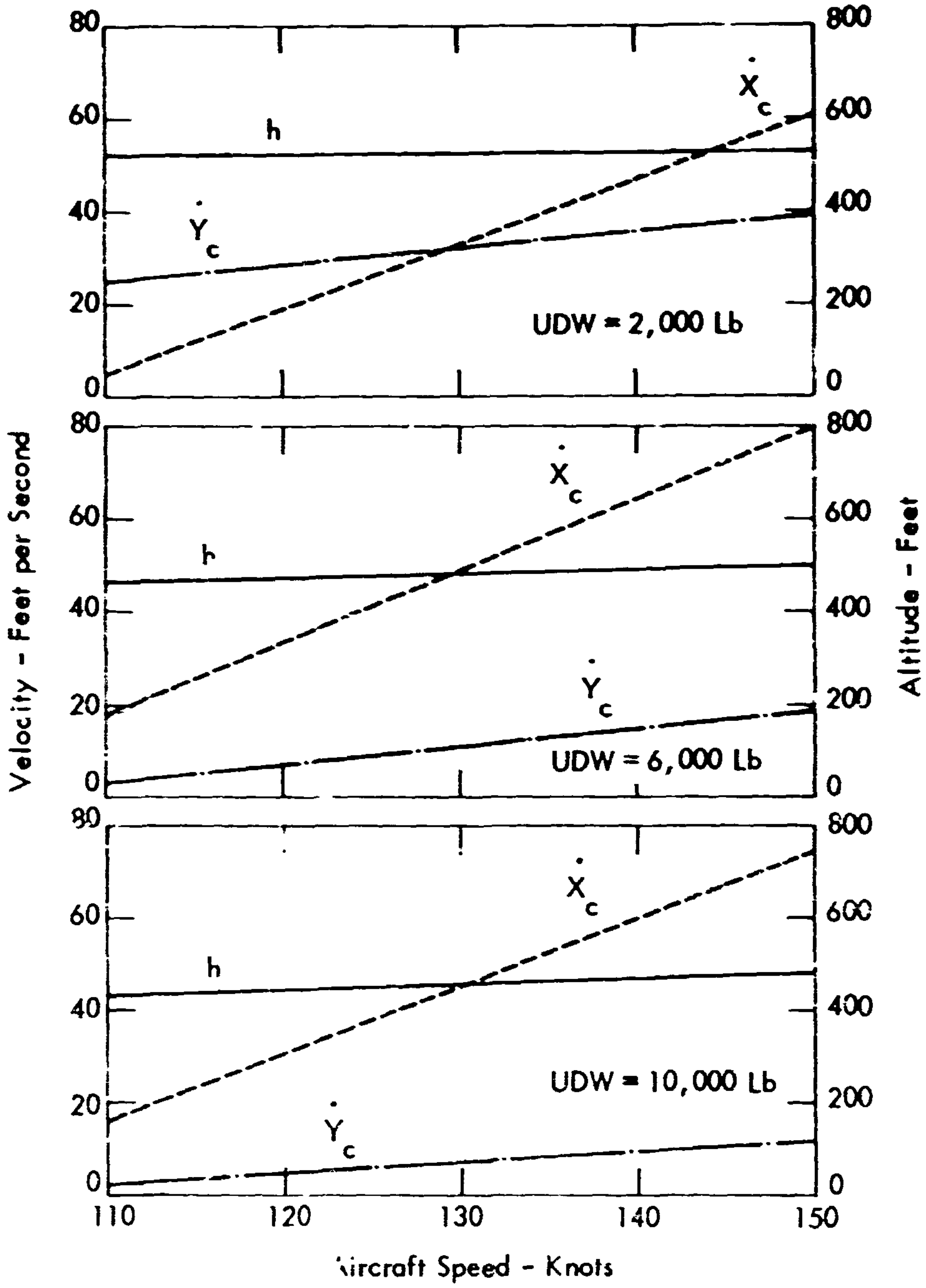


Figure - Analog Results - 2.0 g Extraction Acceleration with 30 Feet per Second Winch Reel-in

h = Drop altitude

$\dot{X}_c$ = Cargo horizontal impact velocity

$\dot{Y}_c$ = Cargo vertical impact velocity

UDW = Unit drop weight

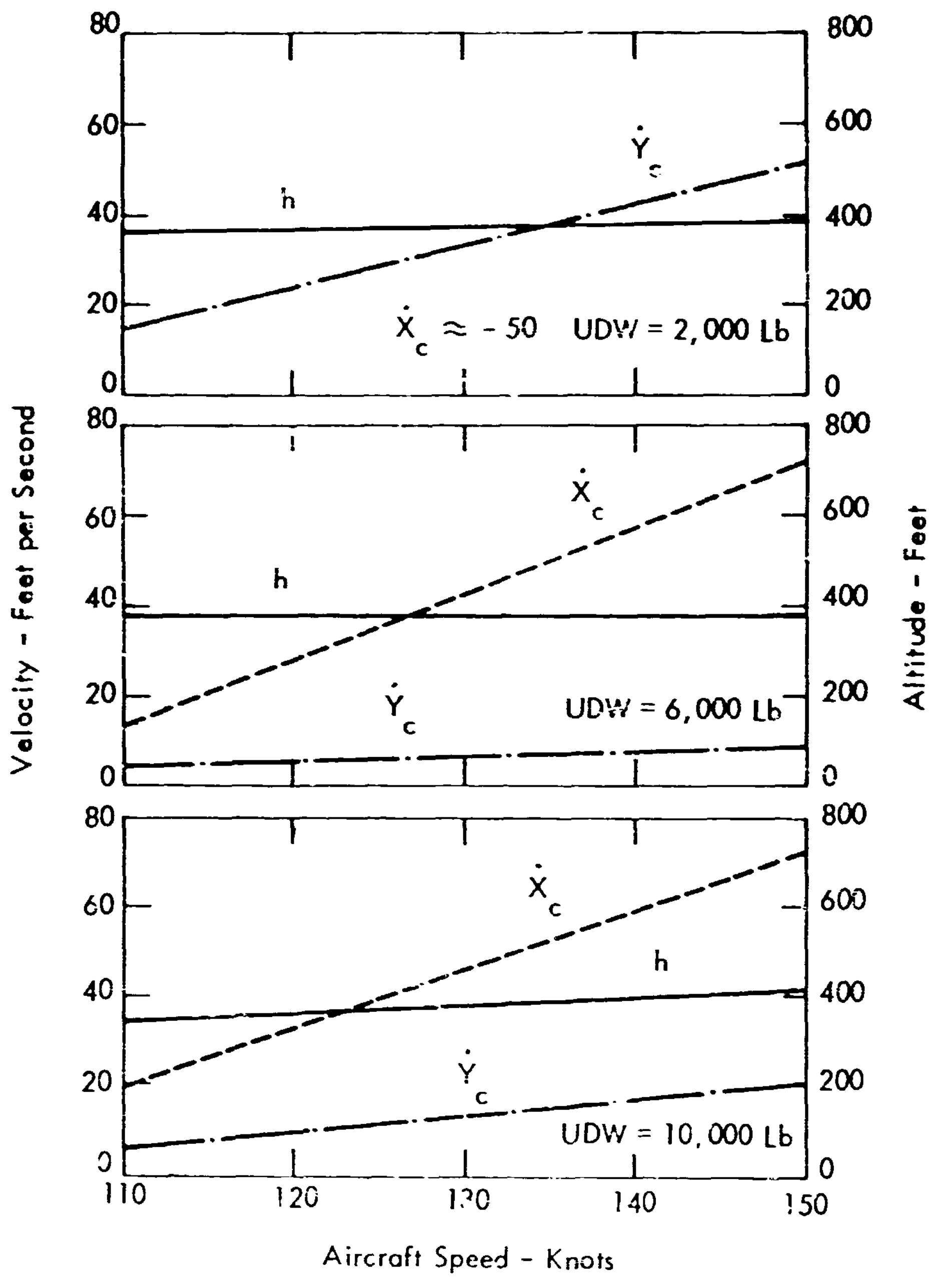


Figure 18 - Analog Results - 3.0 g Extraction Acceleration with 30 Feet per Second Winch Reel-in

h = Drop altitude

$\dot{X}_c$ = Cargo horizontal impact velocity

$\dot{Y}_c$ = Cargo vertical impact velocity

UDW = Unit drop weight

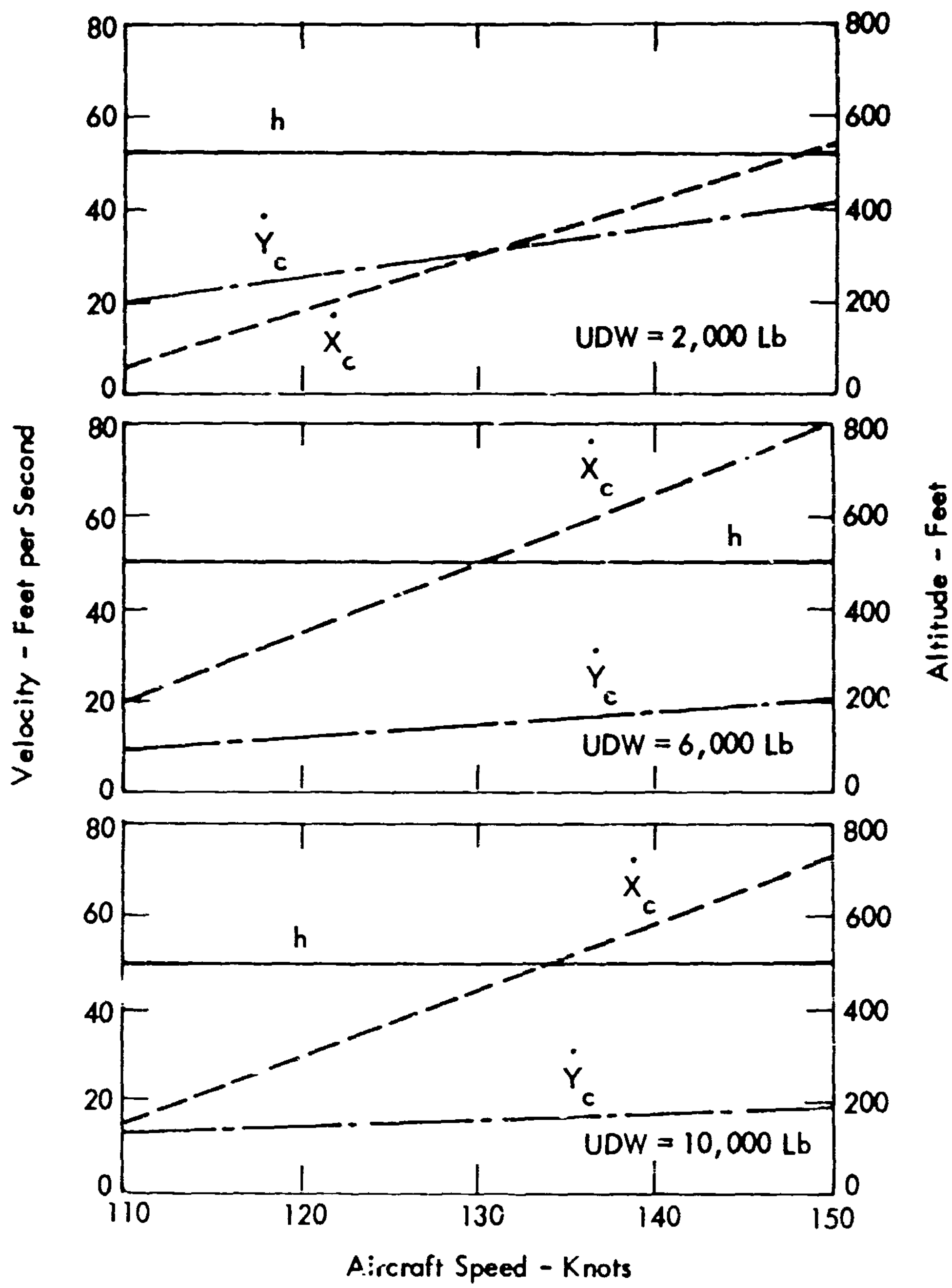


Figure 19 - Analog Results - 2.0 g Extraction Acceleration with 10 Feet per Second Winch Reel-in

h = Drop altitude

$\dot{X}_c$ = Cargo horizontal impact velocity

$\dot{Y}_c$ = Cargo vertical impact velocity

UDW = Unit drop weight

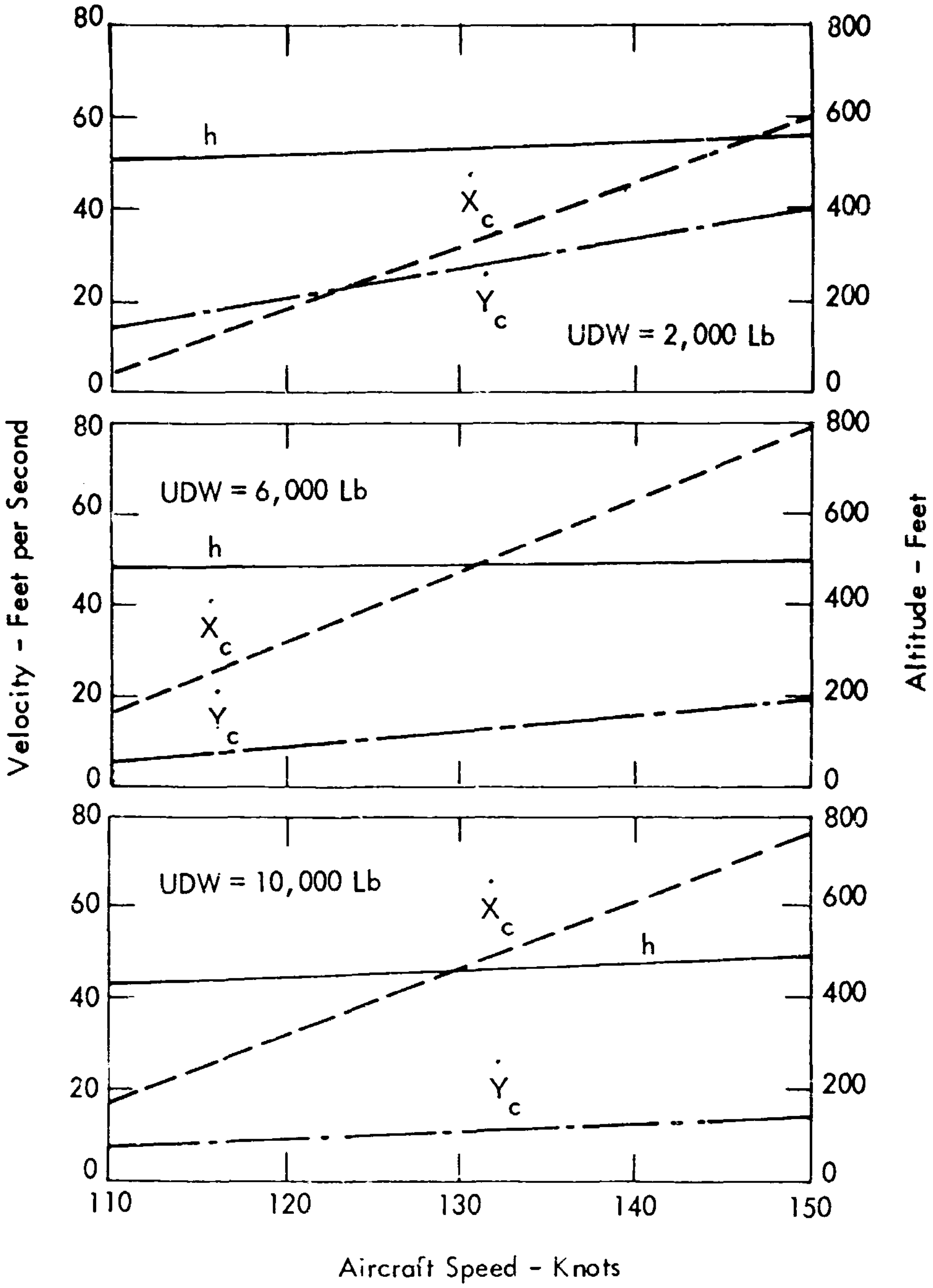


Figure 20- Analog Results - 2.0 g Extraction Acceleration with 20 Feet per Second Winch Reel-in

Figures 17, 19 and 20 should be compared to see the effect of changing winch reel-in rate. These curves show that drop altitude is affected very little but does decrease as reel-in rate increases. Horizontal impact velocity is insensitive to reel-in rate changes. The vertical impact velocity decreases and becomes more sensitive to changes in aircraft velocity as reel-in rate increases.

These analog results assume that all parameters are accurately set for each drop. The Random Error and Accuracy Analyses presented later in this report show what can be expected of Trolley under operational conditions. For all such considerations, it was assumed that cargo extraction would be limited to a 2.0 g-acceleration in order to minimize rigging problems.

In this investigation it was determined that Trolley impact velocities were excessive at 150 knots and that drops at 130 knots were approaching maximum acceptable impact velocities. The Trolley airdrop system appears more attractive in terms of impact velocities and drop altitudes if it is optimized and designed for one particular drop speed such as 120 knots.

Sensitivity Analysis

Analyses were conducted to determine the effect of individual changes in certain variables on Trolley system performance. This was done by selecting those variables which had a significant effect on impact velocities and drop altitudes and altering these one at a time. This allowed an assessment of the importance of each variable on Trolley airdrop. In reality, probably no one variable would deviate from its programmed value independently of others, but this mathematical tool is useful in identifying the importance of obtaining certain accuracies for these significant variables. The random combination of deviations from programmed values for all variables is also very important and is dealt with in the Random Error and Accuracy Analyses section.

The primary criteria used for judging Trolley airdrop acceptability are horizontal and vertical velocities and airdrop altitude. In the sensitivity analysis, those variables that exert significant influence on the three parameters are summarized below with their permissible errors. It is possible to remain within these error limits during Trolley operation.

- o Aircraft velocity - ± 3.9% (± 5 knots @ 130 knots flight speed)
- o Unit drop cargo weight - ± 5.0%
- o Parachute drag - ± 5.0%
- o Parachute position - ± 17.0%

- o Initial cable length - ± 1.5%
- o Cable length at braking - ± 2.4%
- o Time for braking - ± 40.0%

In addition to determining the effect of the above variables on impact velocities and drop altitudes, the effect of an error in drop altitude, within ± 4.0 percent, on the horizontal and vertical impact velocities, was determined. Results of this analysis are presented in Figures 21 through 27. Plotted on the abscissa of each figure is one of the variables mentioned above, and plotted on the ordinate of each figure are horizontal impact velocity, vertical impact velocity, and drop altitude. Figure 21 shows that vertical impact velocity changes very little with aircraft velocity error. Both horizontal impact velocity and drop altitude, however, change measurably with aircraft velocity variations. It is noted from the figure that all three variables plotted on the ordinate assume lower values at the lower aircraft velocities; hence, it can be concluded from the mathematics of the system, as well as from intuitive logic, that lower impact velocities and lower drop altitudes result at the lower aircraft velocities.

Figure 22 shows that the Trolley concept is essentially insensitive to unit drop weight changes within the range of weights shown on the abscissa. The variation of ± 500 pounds in the unit drop weight (10,000 pounds) amounts to a ± 5 percent error allowable in determining that weight.

The error in parachute drag affects the impact velocities and drop altitude as shown in Figure 23. Since parachute drag is the force which extracts the drop cargo, the initial error in parachute drag is directly proportional to an error in extraction acceleration. In this sensitivity analysis, the error of ± 1000 pounds in parachute drag amounts to ± 5.0 percent of the total drag of 20,000 pounds. This also amounts to ± 5.0 percent error in extraction acceleration or ± 0.1 g-error in the nominal 2.0 g-extraction. The drop altitude is measurably affected by this source of error, but impact velocities are relatively insensitive.

Horizontal impact velocity and drop altitude are sensitive to parachute vertical position while vertical velocity appears to be insensitive to the parachute position as shown in Figure 24. Actually, the increase in drop altitude with lower initial parachute position allows for a longer time for vertical velocity to be arrested. If drop altitude were held constant, then vertical velocity would show essentially the same sensitivity to parachute position, but horizontal velocity would be higher. The range of parachute positions investigated (± 20 feet) amounts to about ± 17 percent of the parachute's nominal distance below the airplane.

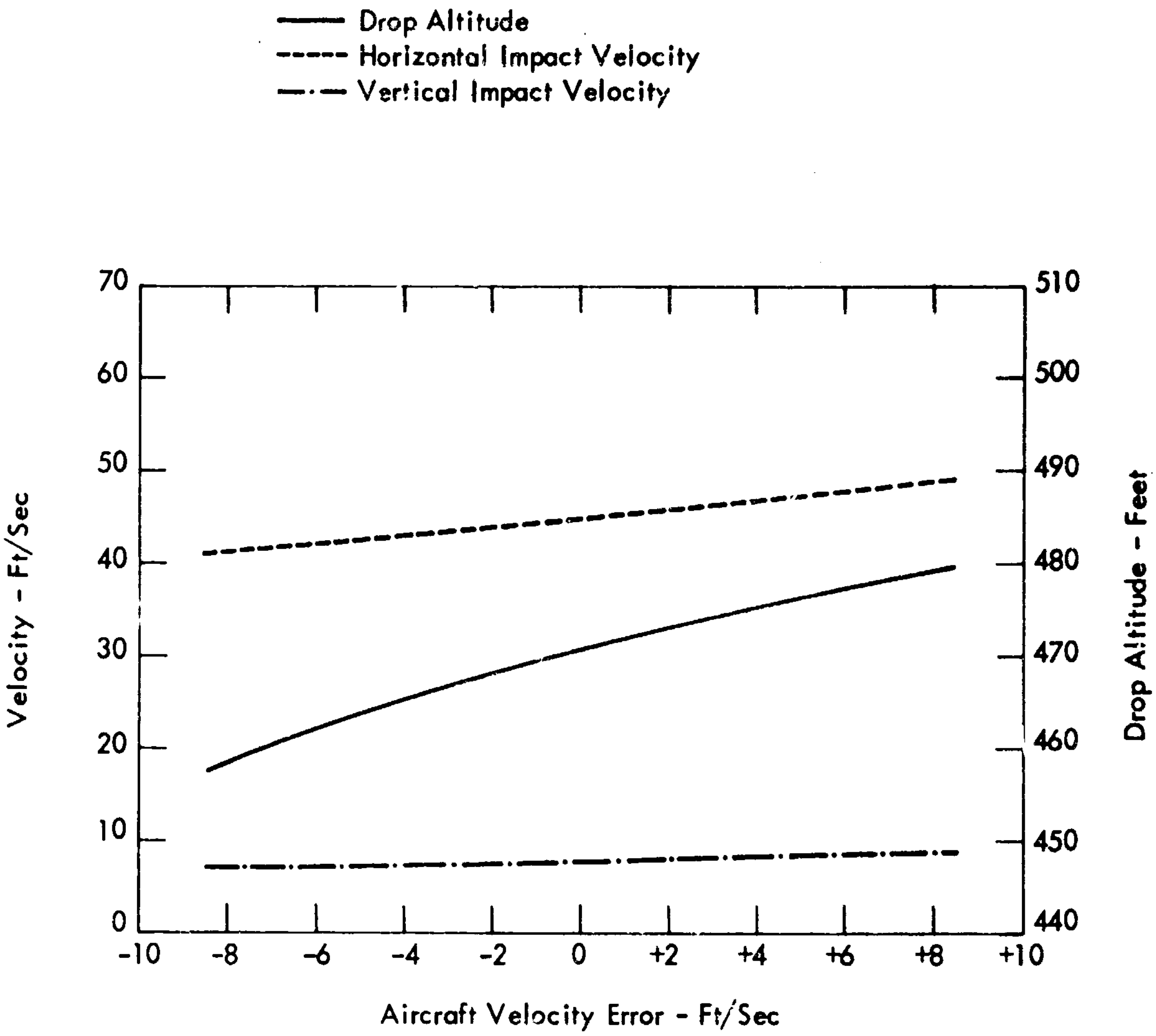


Figure 2[illegible] - Sensitivity to Aircraft Velocity

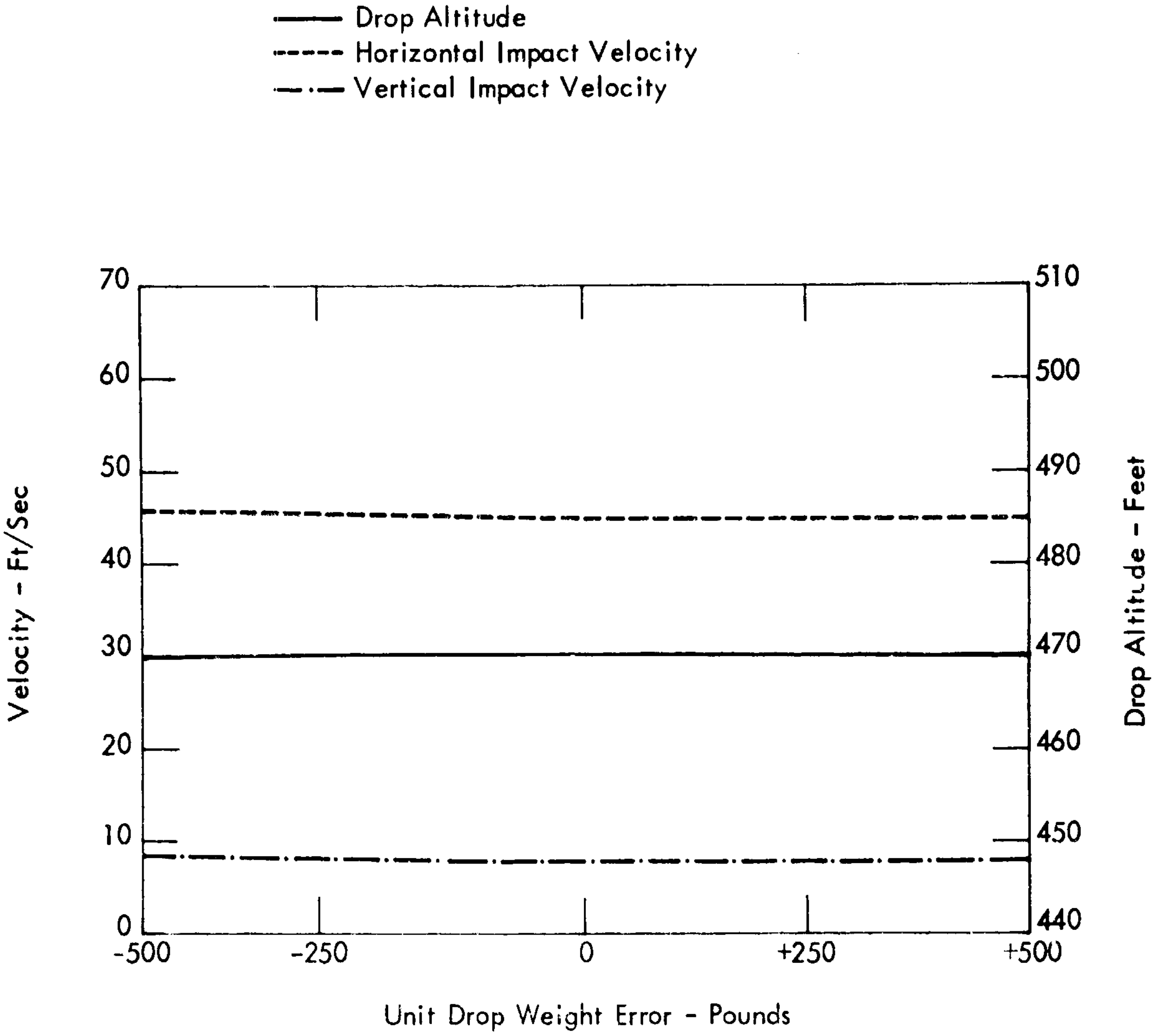


Figure 22 - Sensitivity to Unit Drop Weight

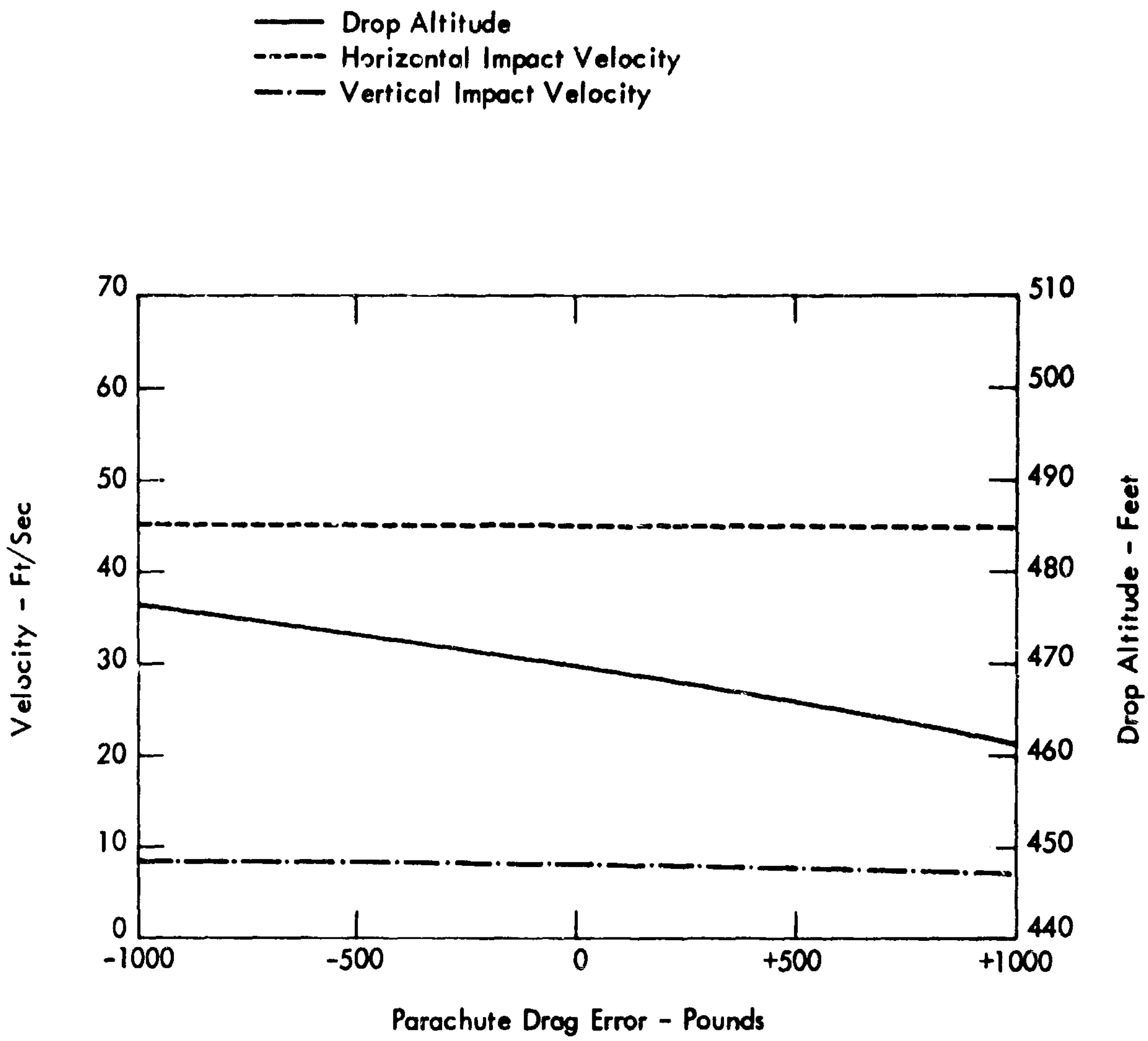


Figure ? - Sensitivity to Parachute Drag

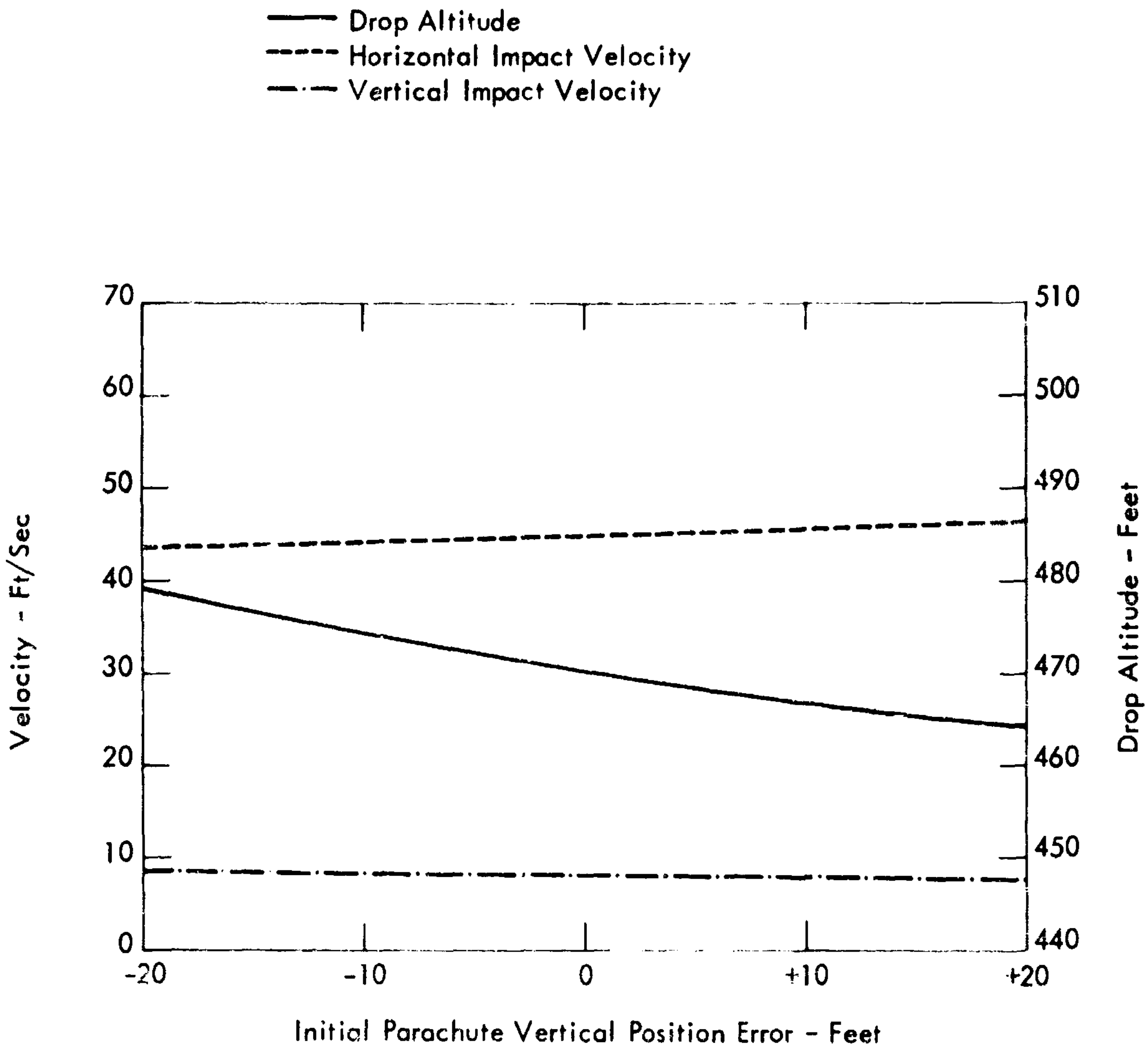


Figure [illegible] - Sensitivity to Parachute Vertical Position

The initial cable length payout of 1300 feet is one variable that should be subject to very little error since its measurement is simple and accurate. An error of $\pm$ 25 feet, or 1.5 percent of cable payout, has only slight effect on drop altitude and essentially no effect on impact velocities as shown in Figure [illegible].

The amount of cable payed out during free fall added to the initial line length amounts to the cable length at braking. As seen in Figure 26, horizontal impact velocity is higher for the shorter payout lengths, and drop altitude is affected in the opposite manner. Vertical velocity shows a continuing increase with additional cable payout. The range of error investigated was $\pm$ 40 feet or 2.4 percent of cable length at braking. Again this is a variable that should be subject to little error.

The braking time error of $\pm$ 0.6 seconds shown in Figure 27 amounts to $\pm$ 40 percent of the nominal 1.5 second braking time. This large possible error was investigated because of the degree of uncertainty concerning repeatability of stopping time for the brake. Fortunately, the Trolley system performance is affected only slightly by this relatively large error.

In Figure 28, the horizontal and vertical impact velocity variations with drop altitude are shown. The altitude error shown is $\pm$ 20 feet or $\pm$ 4 percent of the nominal 500-foot drop altitude. This figure is well within current state-of-the-art radar altimeter accuracies.*

Random Error and Accuracy Analyses

Lockheed feels that the ability of the Trolley concept to provide low impact velocities, to ensure very accurate delivery, and to operate at altitudes below 500 feet are the primary measures of success in tuning the system to meet Army requirements. Certainly, other aspects are important, but the analytical work performed has been geared to obtain desirable values of these three parameters. Therefore, in performing the random error and accuracy analyses, a classification of variables which exert important influence on these parameters was conducted so that their effect on total system operation could be determined. These variables, investigated individually in the sensitivity analysis, were combined in random fashion to determine their total effect on system performance. The investigation of random combinations of these variables is more realistic than an investigation of each variable individually. Those variables determined to have important influence on system operation follow:

*See Operational Analysis and Cost Sections

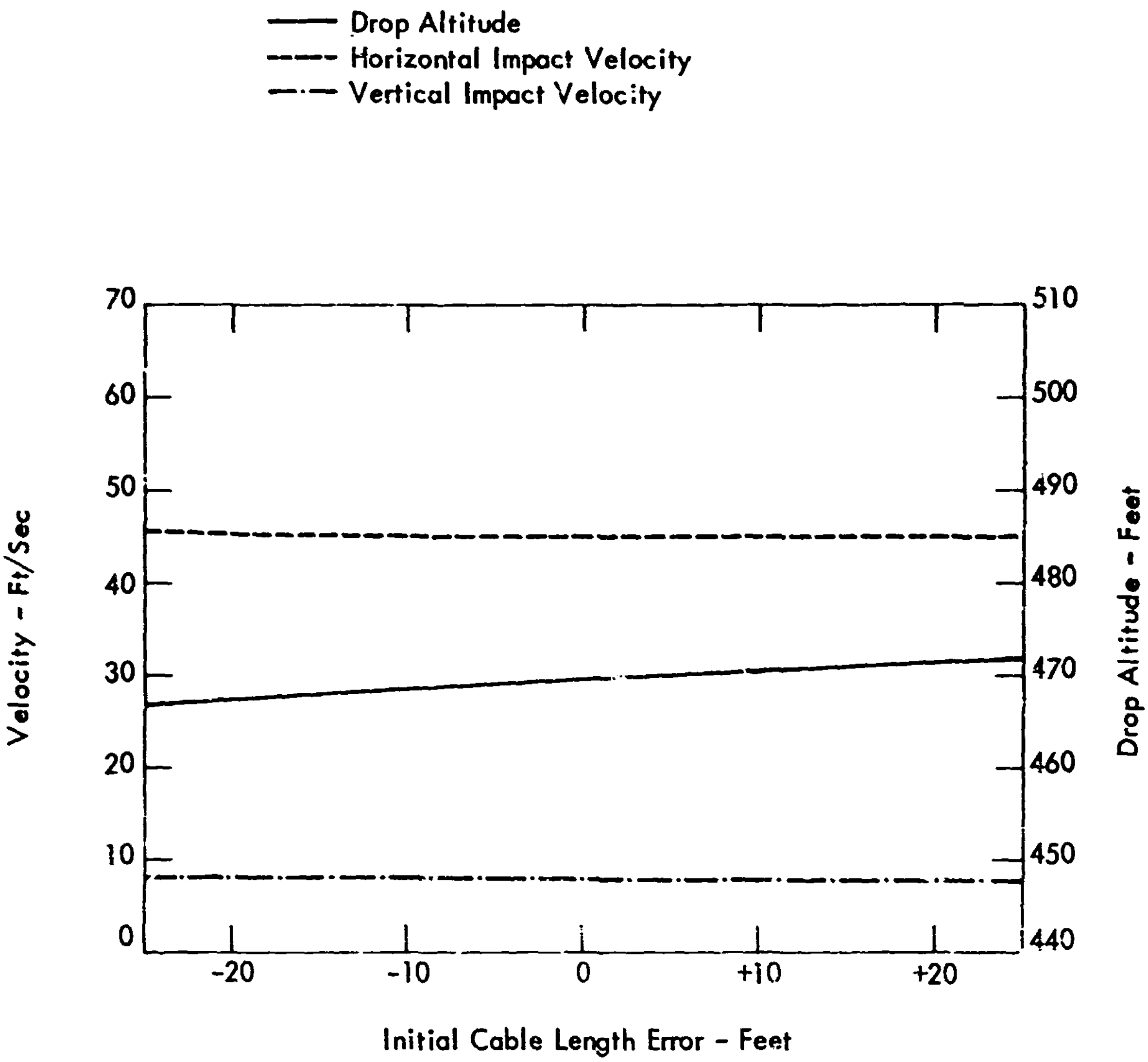


Figure 25 - Sensitivity to Initial Cable Length

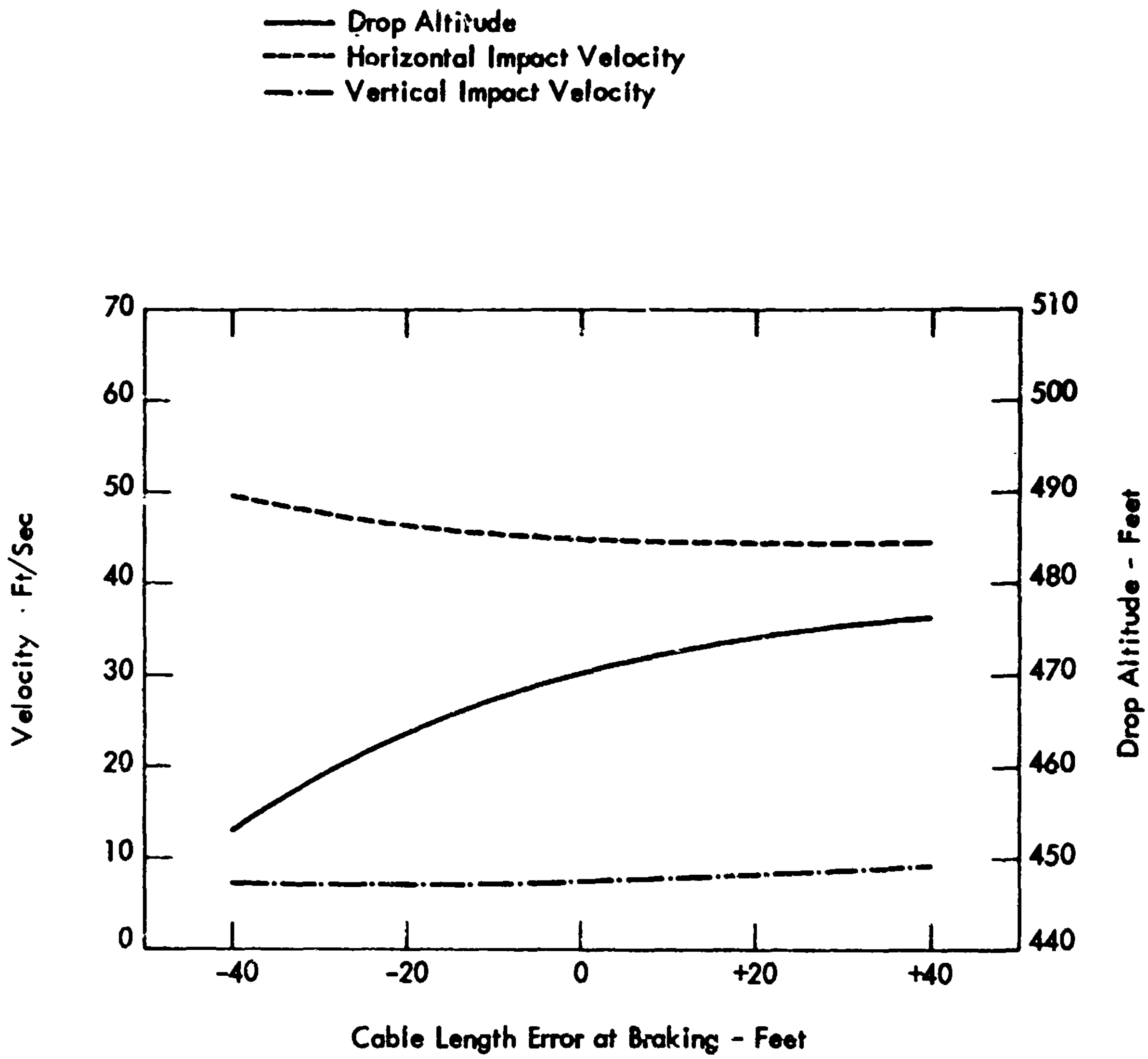


Figure 26 - Sensitivity to Cable Length at Braking

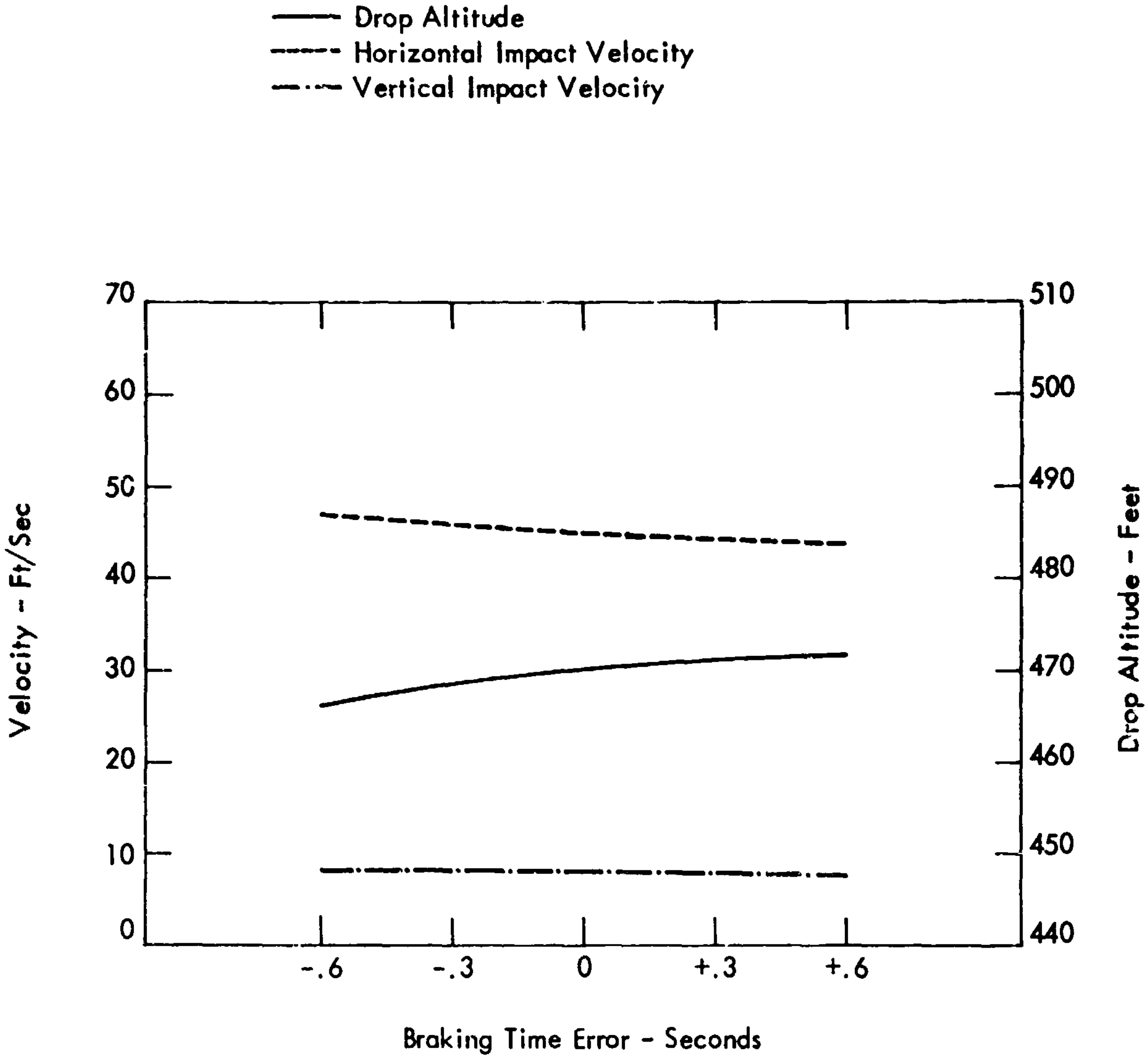


Figure 27 - Sensitivity to Braking Time

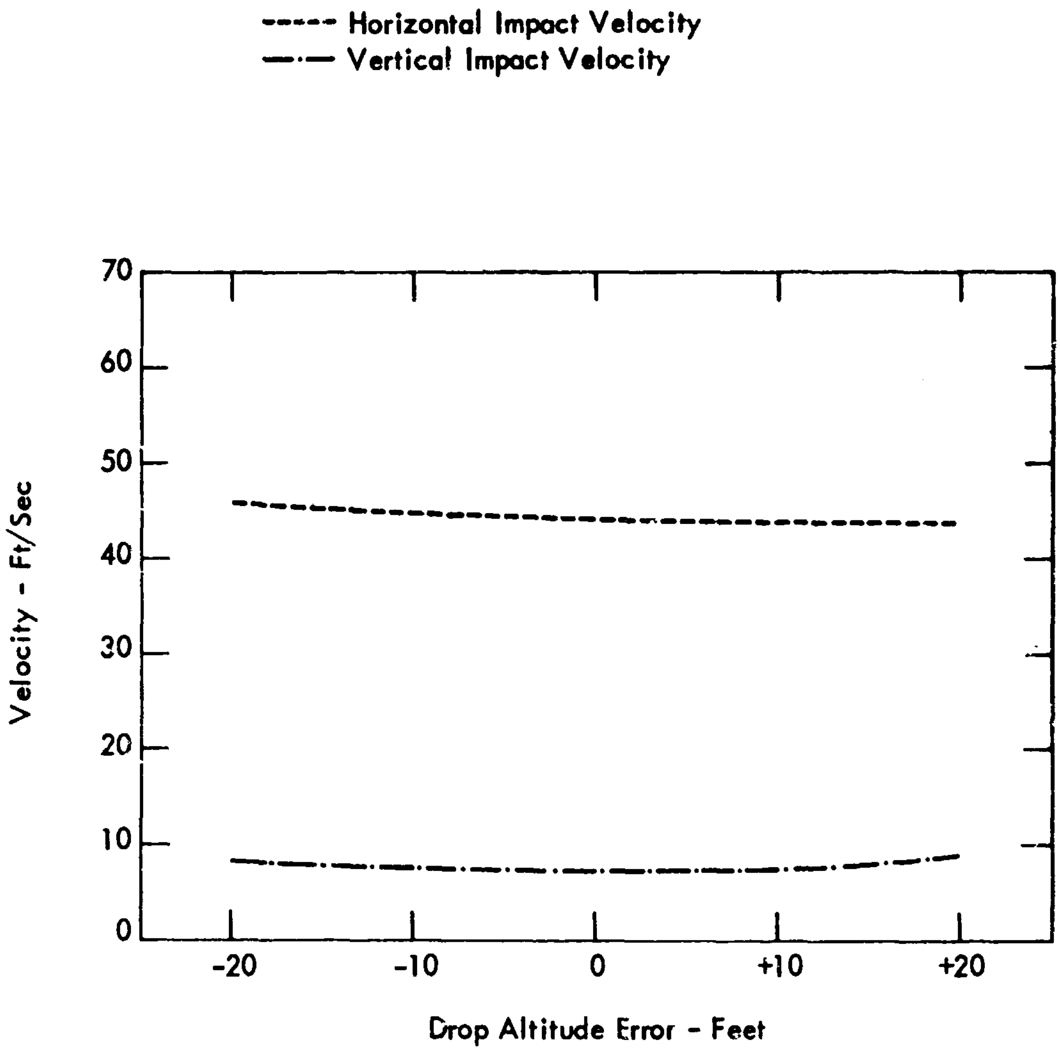


Figure 2 - Sensitivity to Airdrop Altitude

- o Aircraft velocity
- o Unit drop weight
- o Initial cable length
- o Cable length at braking
- o Parachute position
- o Braking time
- o Parachute drag

Since these variables are not all independent, it is a very difficult process to analytically determine their total effect when combined; therefore, the effects of these variables on total system performance were determined by fitting probability distribution curves to each of these variables and randomly sampling a value for each variable to input to the digital computer program. This method allows computer output data to be treated essentially as "test" data, and it utilizes the random sampling technique developed by the Rand Corporation.* For the purposes of this analysis, 30 computer runs were made by using inputs randomly sampled, and the output data were treated as test data. It should be noted that one fundamental principle of statistics is that precision improves in proportion to the square root of the number of measurements in the sample. With more samples, greater accuracy could be obtained but with less return in accuracy compared to the effort required for additional data. It is felt that the accuracy obtained is compatible with other results in this study and that further random sampling and computing would gain little or nothing.

The significant results obtained in this analyses are summarized below.

110 knots:

Accuracy

- o Within 78 feet of target impact point

Random error

- o Vertical impact velocity - 1.5 to 3.2 fps
- o Horizontal impact velocity - 14.5 to 20.0 fps
- o Drop altitude - 420 to 465 feet

130 knots:

Accuracy

- o Within 90 feet of target impact point

*The RAND Corporation. A Million Random Digits. The Free Press, Glencoe. 1955

Random error

- o Vertical velocity - 6.0 to 9.5 fps
- o Horizontal impact velocity - 41.0 to 49.0 fps
- o Drop altitude - 450 to 485 feet

Figure 29 shows the range of values expected for vertical impact velocity, horizontal impact velocity, and drop altitude for all drops subject to the following conditions:

- o Aircraft velocity - 110 knots
- o Unit drop weight - 10,000 pounds
- o Extraction acceleration - 2.0 g's

By following the dotted line on Figure 29 one can conclude that in 80 percent of the airdrops vertical impact velocity will exceed 2.3 feet per second, horizontal impact velocity will exceed 16.8 feet per second, and airdrop altitude will exceed 434 feet. Conversely, in 20 percent of these airdrops, vertical impact velocity will be below 2.3 feet per second, horizontal velocity will be below 16.8 feet per second, and airdrop altitude will be below 434 feet.

The next curve, Figure 30, is identical to the preceding one except that aircraft velocity is 130 knots. By making the same observations from this curve, it can be seen that in 80 percent of these airdrops vertical impact velocity will exceed 7.4 feet per second, horizontal impact velocity will exceed 43.2 feet per second, and airdrop altitude will exceed 458 feet. Conversely, in 20 percent of the drops vertical impact velocity will be below 7.4 feet per second, horizontal impact velocity will be below 43.2 feet per second, and drop altitude will be below 458 feet.

Figure 31 shows predicted impact point dispersal for 110-knot aircraft speed, and Figure 32 shows the same for an aircraft speed of 130 knots. It is interesting to note that the drop cargo tends to overshoot the predicted impact point more than it tends to undershoot and that the greatest miss distance is also on the overshoot side.

Lateral miss distance is caused only by the fact that the parachute tow cable is at an angle with the aircraft track across the drop zone when crosswind is present. Since early or late impact of the cargo can be thought of as an error in cargo position on the cable at the time of touchdown, this cargo position error can be resolved into errors

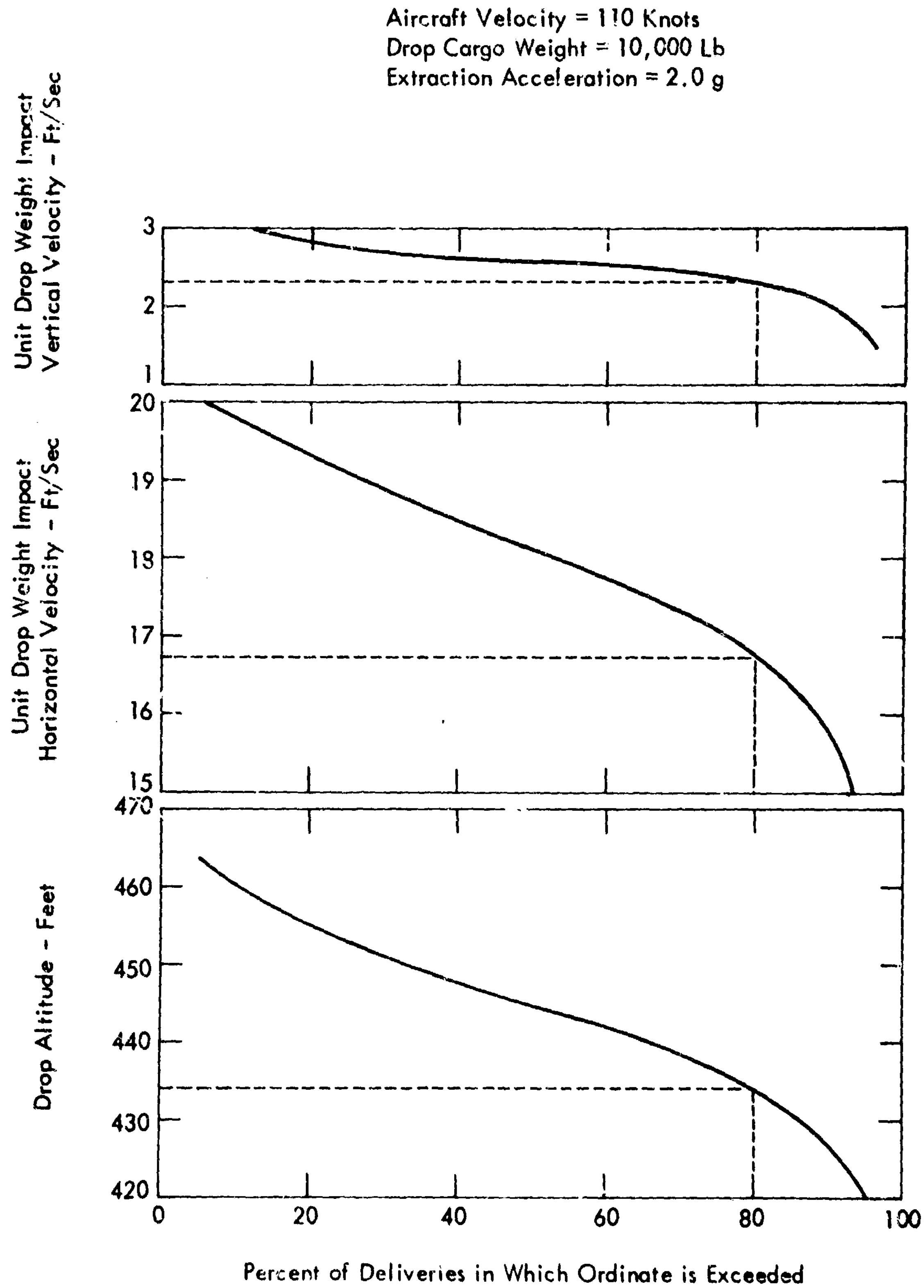


Figure - Random Error Results - 110 Knots

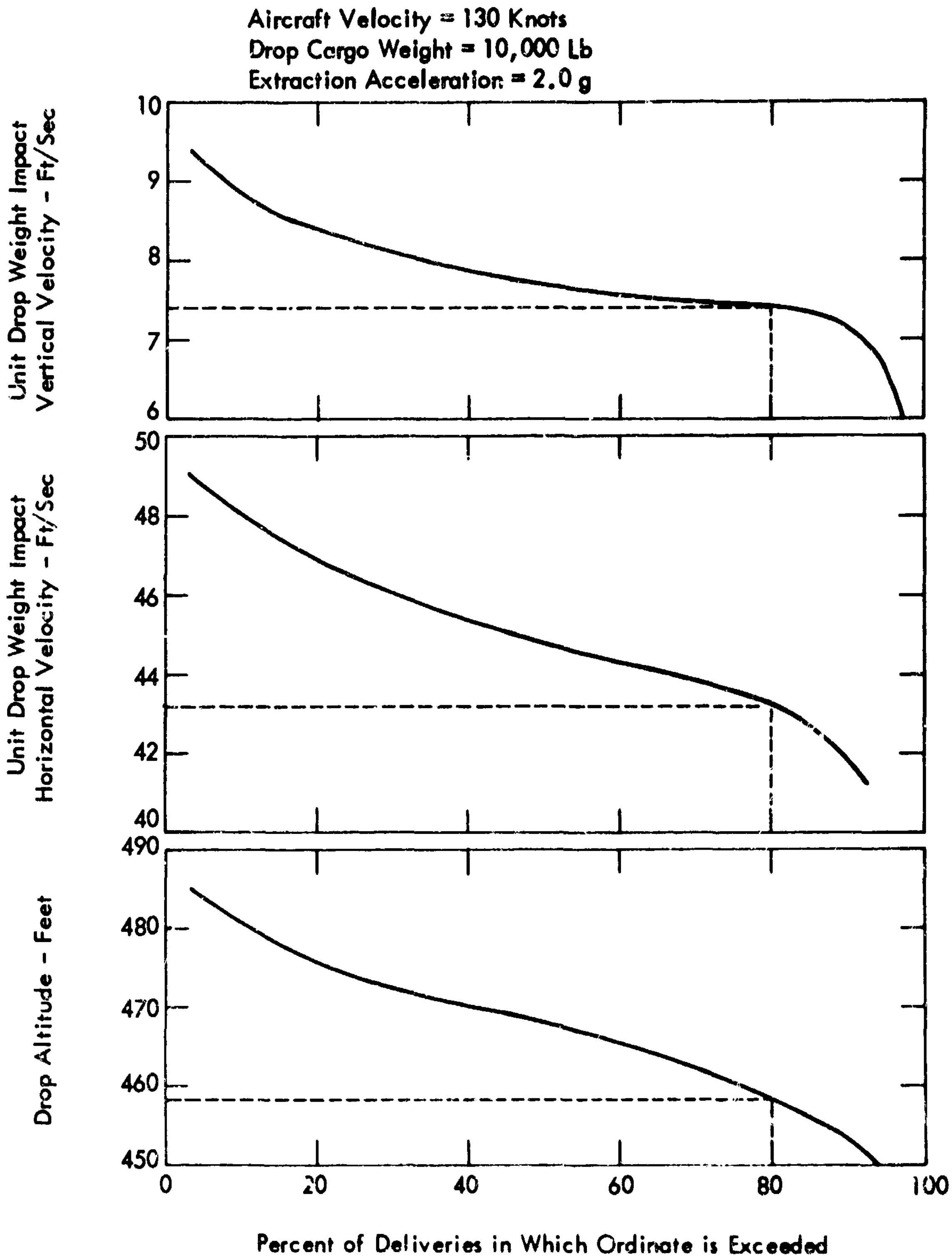


Figure 30 - Random Error Results - 130 Knots

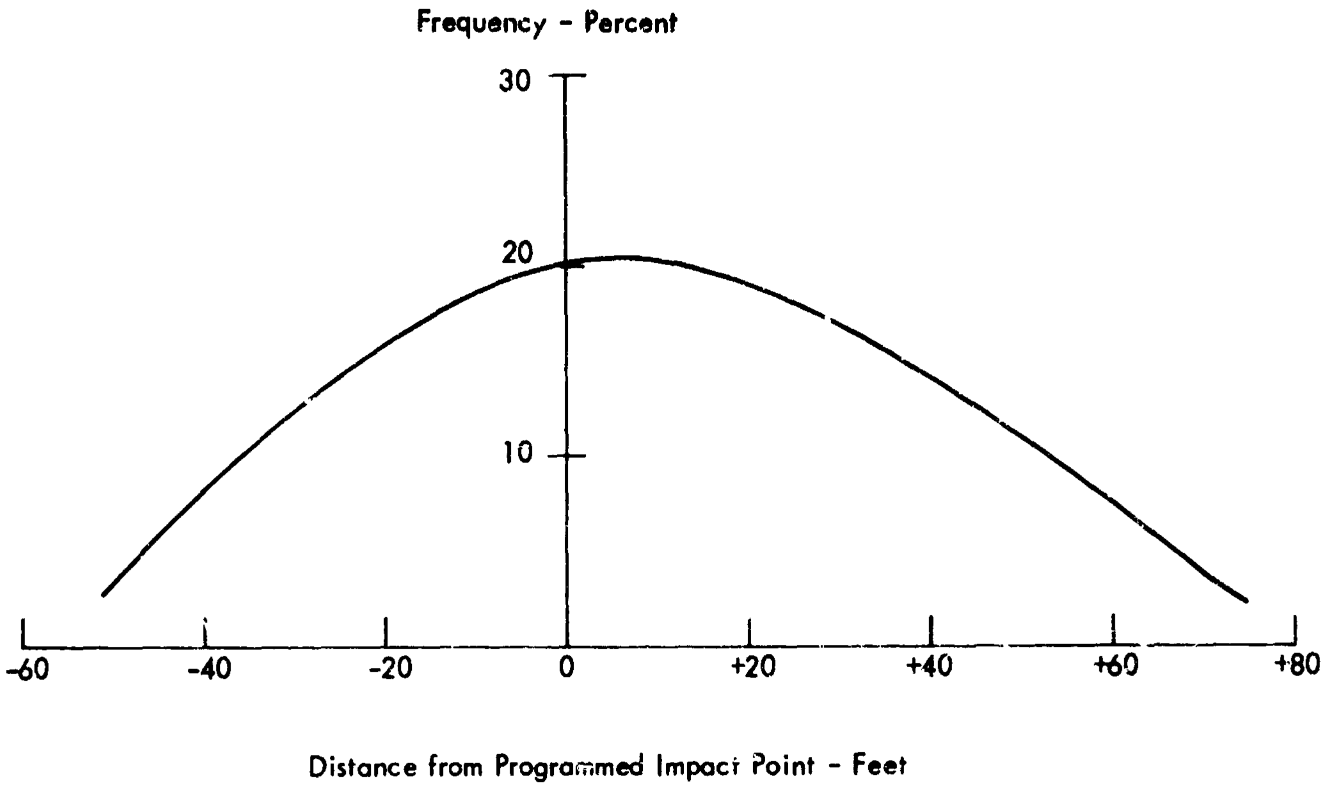


Figure 31- Predicted Airdrop Accuracy - 110 Knots

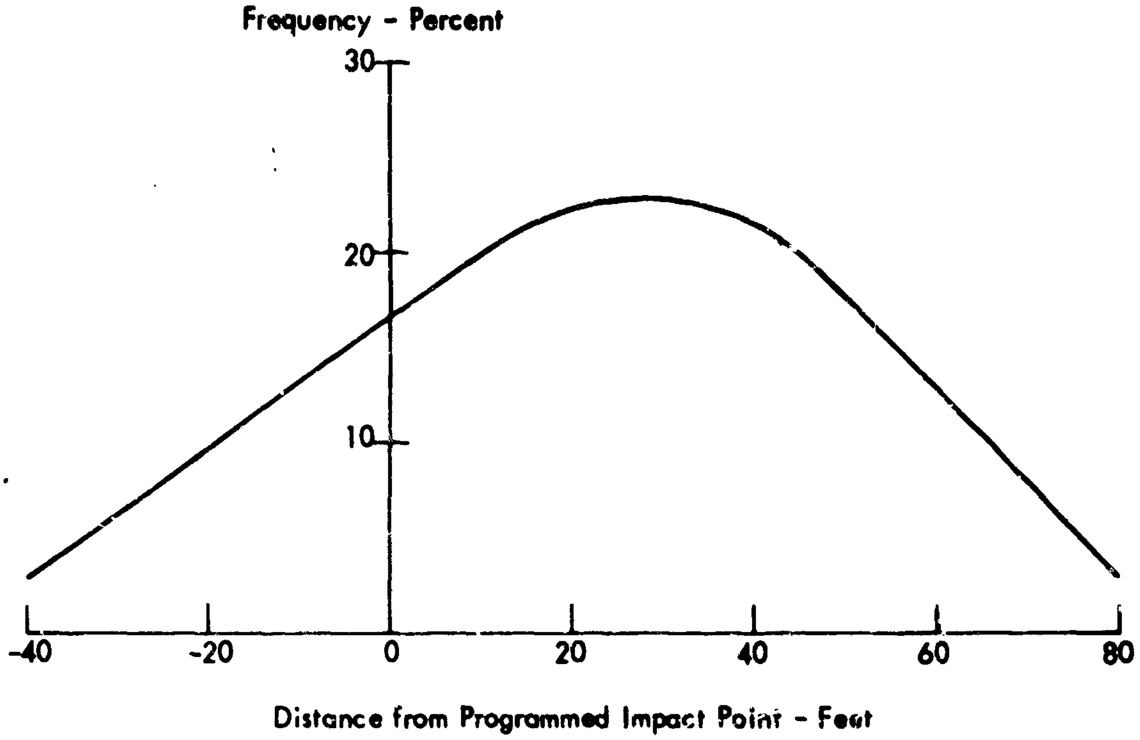


Figure [illegible]2- Predicted Airdrop Accuracy - 130 Knots

parallel and perpendicular to the aircraft track across the drop zone. When the cable angle is considered for a 15-knot, 90-degree crosswind at both 110 and 130-knot aircraft speeds, the lateral miss distance is approximately ± 9 feet. Thus, the resulting drop zone is eliptical in shape with the semi-minor axis of the ellipse being only about 9 feet. This analysis assumes accurate prediction of winds at drop altitude only; the wind profile from drop altitude to the ground is of minor importance.

OPERATIONAL ANALYSIS

The definition of major hardware components for the Trolley concept has been completed. With the Trolley concept the C-130E is capable of delivering a 2000 to 10,000-pound unit drop weight with no modification of aircraft structure. Minor changes to electrical or hydraulic adaptors may be required during hardware development to satisfy system (winch and control) power requirements. Retrofit of present C-130 radar altimeters with an improved radar altimeter, which is currently available, will ensure system accuracy and reliability. Reduction in gross rigging requirements, such as airdrop cargo preparation, hardware to attach cargo to platform, rigged airdrop cargo weight, and personnel training, have been identified without any significant deviations having to be made from current rigging procedures. Data have been developed to define drop zone requirements for airdrop from single and formation aircraft. Check list changes in operating procedures for airdrop during single and multiple passes have also been identified.

Compatibility of the Trolley concept with C-141A and CV-7A aircraft has been investigated to determine unit cargo drop weight capabilities and major hardware components. Unit cargo drop weight capability for the CV-2 could not be determined due to non-availability of detailed aircraft performance data (power available versus power required). An estimate of CV-2 compatibility was made by comparing it with CV-7A data.

C-130 Unit Cargo Drop Weight Capability

The 2000 to 10,000-pound airdrop capability of the C-130 aircraft at sea level and standard atmosphere is reduced at higher altitude and temperature. Figures 33, 34, and 35 present the excess thrust available for different altitude and temperature combinations for a C-130 flying at 90,000, 100,000, and 110,000-pound gross weights and at 110 to 150 knots (EAS). An approximate 50 percent reduction in excess thrust is experienced when the aircraft is flying at a 5000-foot altitude and at a temperature of 100°F. Since unit cargo drop weight capability is one-half of the excess thrust available, a maximum of 5000 pounds can be air-dropped with the Trolley concept from a C-130 flying at the 5000-foot and 100°F condition.

System Equipment and Operation

Major components which make up the proposed Trolley system include equipment presently installed in the C-130, readily available off-the-shelf hardware, and hardware which requires further development. Design and operational criteria have been determined for hardware development and application. Components are identified as follows:

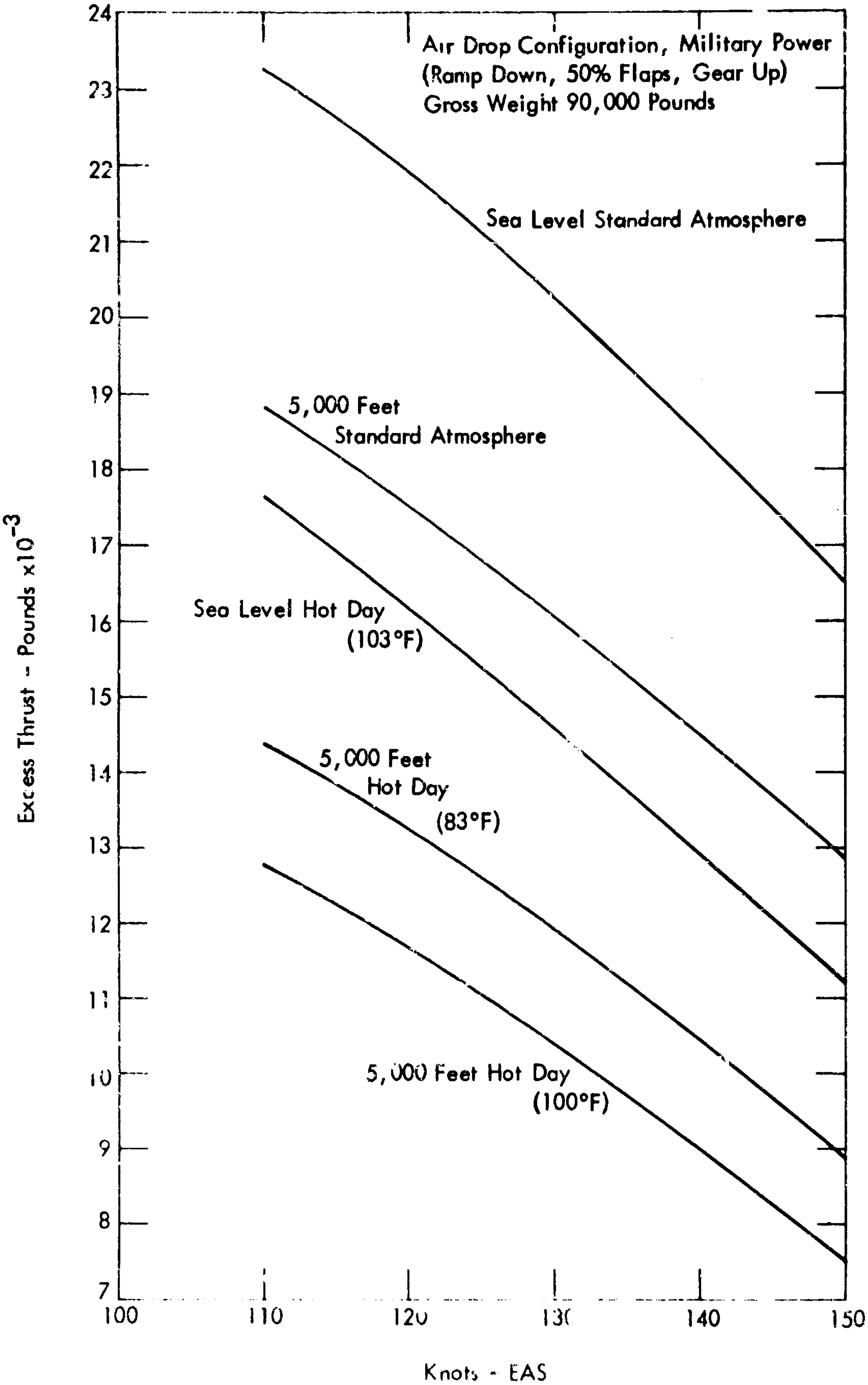


Figure 33 - C-130E Excess Thrust Available at 90,000 Pounds Gross Weight

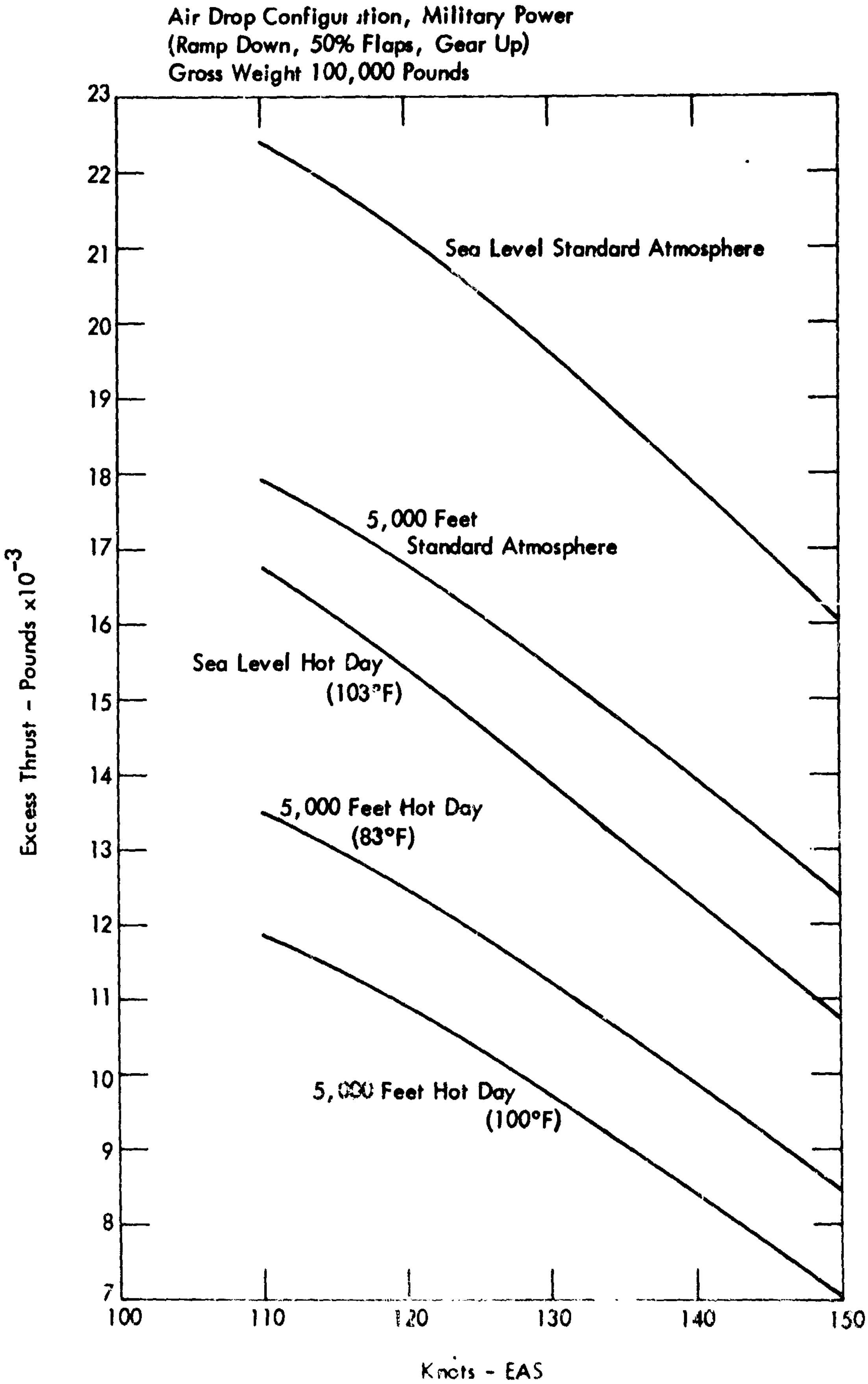


Figure 34 - C-130E Excess Thrust Available at 100,000 Pounds Gross Weight

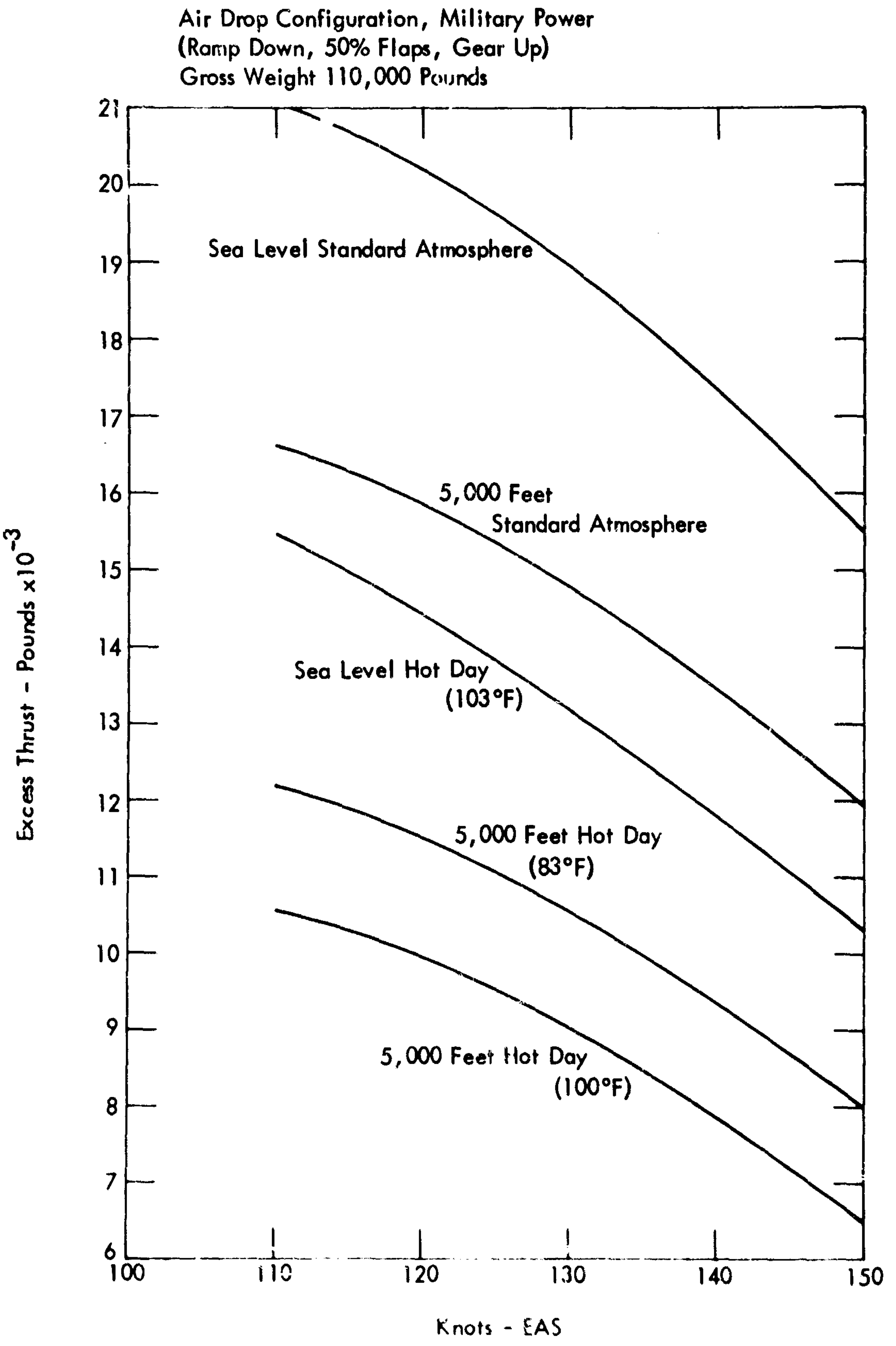


Figure 35 - C-130E Excess Thrust Available at 110,000 Pounds Gross Weight

o Winch and Control, Platform Mounted	Development
o Cable	Development
o Trolley Slide	Development
o Cable and Trolley Guide Rail	Development
o Drag Parachute	Available
o Cargo Rigging	Available
o Cable Guillotine	Available
o Drogue	Development
o Radar Altimeter	Retrofit

The following equipment utilized during Trolley airdrop operation is presently used in the C-130 aircraft and is not peculiar to the Trolley system:

o Dual-Rail Cargo Handling System with Modular Platforms	No change
o Pendulum System	No change
o Sighting Device	No change

<u>Winch and Control</u> - The winch and its control constitute the major components of the Trolley system. The primary functions are to store, reel-out, reel-in, maintain desired cable tension, and brake the cable to a stop during equipment airdrop. In addition, normal cargo loading/unloading ground operations can be accomplished with the Trolley winch. The design concept for a hydraulic or electric-powered winch shown in Figure 36 includes a drum, level-wind device, flywheel, brake, gear box, and control panel. Two thousand feet of 3/4-inch diameter swaged cable are stored in three layers on a drum 3 feet in diameter and 36 inches wide. A maximum drum speed of 1400 revolutions per minute is attained during cable reel-out when the cable attains speeds up to 225 feet per second. Peak power requirements occur during reel-in of the cable and drag parachute at cable velocities reaching 40 feet per second at 1.8-g cable tension (maximum 18,000 pounds). Peak energy requirements for the 4-second reel-in period are augmented by kinetic energy stored in a 3-foot diameter flywheel weighing 1000 to 1500 pounds and operating at 3000 to 3500 revolutions per minute and geared to the drum. The flywheel is also utilized during rapid reel-in to reposition the parachute for subsequent airdrop or to recover

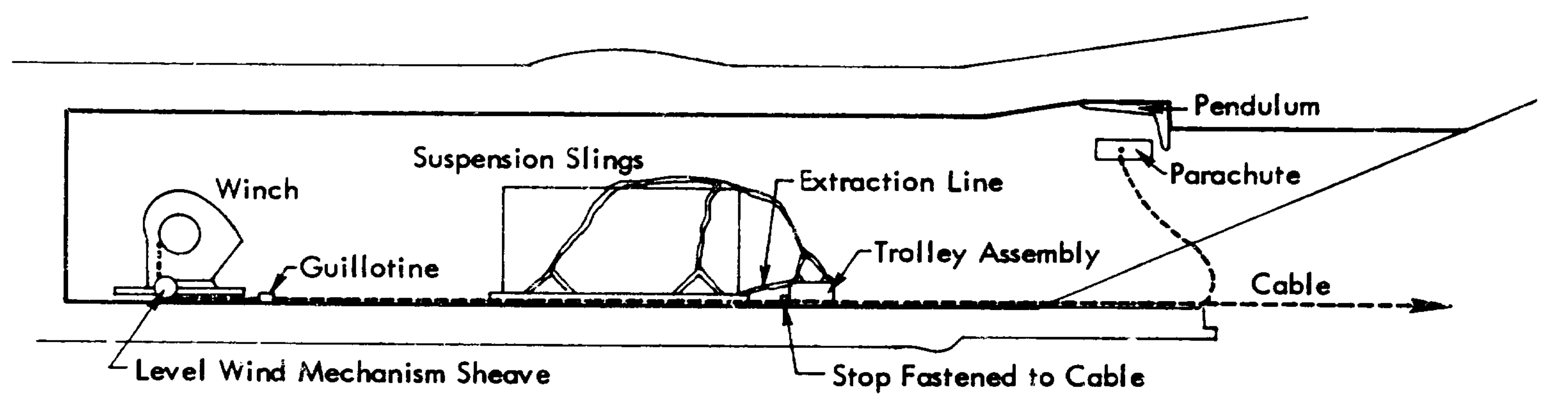


Figure 36- Inboard Profile of Trolley in C-130

the cable and collapsed parachute after the final drop. An aircraft brake adapted to the winch drum provides friction force to overcome up to 31,000 pounds of cable tension during the 1.5-second braking cycle.

The loadmaster's control panel mounted on the winch housing includes a simple mechanical timer which governs the operational sequence of the drum by directing power, flywheel engagement, and brake application as required. A 1.8-g cable tension is maintained by the control during the 4-second reel-in of the cable about 8 seconds after initiation of drop. The tension control is calibrated for unit cargo drop weights from 2000 to 10,000 pounds and is set at the loadmaster's control panel prior to each airdrop.

Winch component parts such as the drum, flywheel, and brake are shielded or enclosed in a housing. The 3500-pound winch assembly is mounted on a 48 by 108-inch pallet at the most forward position of the dual rail system. Extraction is initiated by the copilot releasing the winch brake with a switch located on the flight deck. A second switch, located on the loadmaster's control panel, provides a backup capability and permits the copilot's switch to be inactivated during the loadmaster's airborne check of Trolley when brake release would be hazardous.

Although the winch operating requirements are specific and demanding, the design specifications are well within the current state of the art. Qualified vendors have reviewed the design criteria and have indicated that normal hardware development of a prototype winch with control can be completed in 6 to 9 months. Production units in operational quantities would follow in another 6 months.

Cable - The swaged cable, which is the link between the winch and the drag parachute, transfers the parachute drag force to the Trolley slide assembly which is attached to the drop cargo. After braking, the Trolley assembly and drop cargo slide down the cable to the ground. Cable type and size are dictated by nominal, peak, and dynamic operational tensile loads and by surface smoothness. Two thousand feet of swaged 3/4-inch diameter, 19 x 7 cable weighing 1950 pounds with a minimum breaking strength of 48,000 pounds will satisfy design requirements with a 1.5 safety factor. The swaged cable with a smooth outer surface for improved sliding efficiency, can be developed and delivered by a vendor within 120 days. A standard 18 x 7 non-rotating cable with a less-desirable, rougher outer surface is presently available in 2000-foot lengths.

Trolley Slide Assembly - The Trolley slide assembly has three main functions:

- To provide attaching points for extraction lines and slings

- To transfer cable force to extract the rigged platform from the aircraft

- To lower the sling-attached drag cargo to the ground by its sliding down the cable.

In addition, the assembly disengages itself from the cable after ground impact of the platform and falls to the ground in a condition suitable for reuse.

The design concept for the split slide assembly, presented in Figure 37, includes a teflon-lined cable slot, tapered hole, two locking clip grooves, and two eyebolts. The total weight is approximately 33 pounds. Not shown is a mechanical locking device plunger and spring-loaded hinge. This design concept enables the cable to be inserted into the split cable-slot of the slide and to be kept in place by closing the slot and securing the spring-loaded hinge with the lock. The slide and cable are inserted into the cable and Trolley guide rail through one of the openings provided with the eyebolts on top and the tapered hole facing toward the winch. The slide assembly is retained in place by inserting the locking clip in the matching grooves and closing the opening in the guide rail. The initial 1300 feet of cable deployed with the drag parachute passes freely through the cable slot. As seen on Figure 37, a tapered stop (split for ease of installation) is attached to the cable and fits into the matching tapered hole in the slide assembly end nearest the winch. The wedging action of the tapered stop in the matching hole results in an increase in the cable gripping force as tension produced by the drag parachute is increased. The slide assembly rotates around the cable 180 degrees (suspension eyebolts below the cable) and slides down the cable after leaving the cargo compartment.

The slide is released from the drop cargo by the cargo parachute release mechanism activated by platform ground impact and continues to slide down the cable toward a stop fastened 10 feet from the end of the cable. On contact with the stop, a mechanical plunger releases the lock, which allows the spring-loaded hinge to open. The slide assembly free falls to the ground without striking the platform or drop cargo and can be recovered. The mechanical plunger also serves as a backup platform release mechanism in the event the platform does not touch the ground prior to slide assembly contact with the stop. During a hardware development program, the function performed by the standard cargo parachute release could be engineered as an integral function of the slide assembly.

<u>Drogue</u> - The function of the drogue is to slide down the cable and activate a mechanism to collapse the parachute after airdrop. A

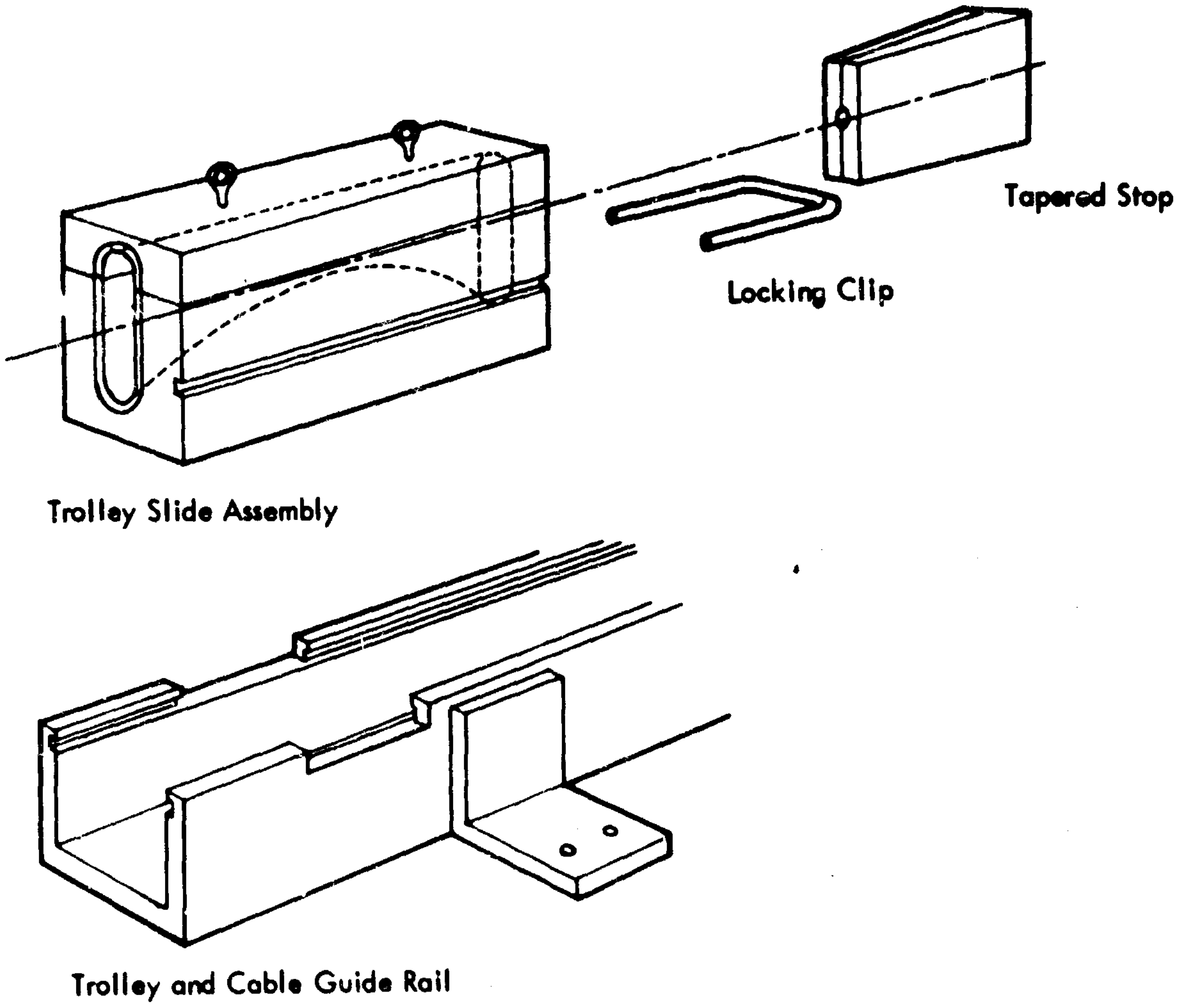


Figure - Preliminary Sketch - Trolley Slide and Guide Rail

collapsed parachute permits recovery of the cable and parachute with minimum winch power requirements. Modification of existing drogues will be conducted during hardware development. Estimated weight of a drogue is 25 pounds.

<u>Cable and Trolley Guide</u> - The functions of the cable and trolley guide are to house the cable from the forward end of the cargo floor to the edge of the cargo ramp and to provide positive guidance to the slide assembly during cargo extraction. The slide assembly, with the cable routed through the cable slot, is contained within the guide rail channel with sliding lock clips. The removable guide rail shown in Figures 38 and 39 is mounted off-center with respect to cargo compartment centerline (so the platform will fall to the same side of the cable each time), and is secured to the floor by use of center tie down fittings. Two sheaves are located forward of the guide rail to provide a bearing surface and remove the lateral force component produced by the cable level wind mechanism. The cable is routed through a cartridge-operated cable guillotine (for emergency use only) mounted on the floor between the sheaves and the guide rail. Several cutout openings with cover plates are spaced along the guide rail to facilitate insertion of the slide assemblies for varying platform lengths and combinations. Estimated weight of the guide rail, sheaves, and guillotine is 295 pounds.

<u>Drag Parachute</u> - Two standard reefed and unreefed 22 and 35-foot diameter ring-slot cargo extraction parachutes produce the range of drag forces required for 2.0 g-extraction while 2000 to 10,000-pound unit cargo drop weights are being airdropped. Reefing line lengths (circumference) for sea level operation have been computed for 22, 28, and 35-foot diameter ring-slot parachutes to provide operational flexibility and are shown in Table [illegible]. Although parachutes of this type can be reefed down to 10 percent of nominal canopy diameter ($D_R/D_o = 0.1$), reefing line lengths were determined so that the parachutes would not drop below 20 percent of nominal canopy diameter ($D_R/D_o = 0.2$). Air Force flight testing conducted at El Centro NAF, California indicates that actual drag forces realized by this type parachute are slightly less than the calculated drag force or those obtained in wind tunnel testing at Wright Patterson AFB, Ohio. However, the drag produced by the deployed cable can be utilized to make up the difference in drag; minor revisions to the tabulated results could be made as a result of prototype flight testing. The reefing diameter must also be increased above that specified for sea level when the same unit drop weight is being dropped at other altitudes.

<u>Pendulum</u> - The pendulum system presently installed in the C-130 is utilized in deployment of the ring slot extraction parachute and no modification is required to the current configuration.

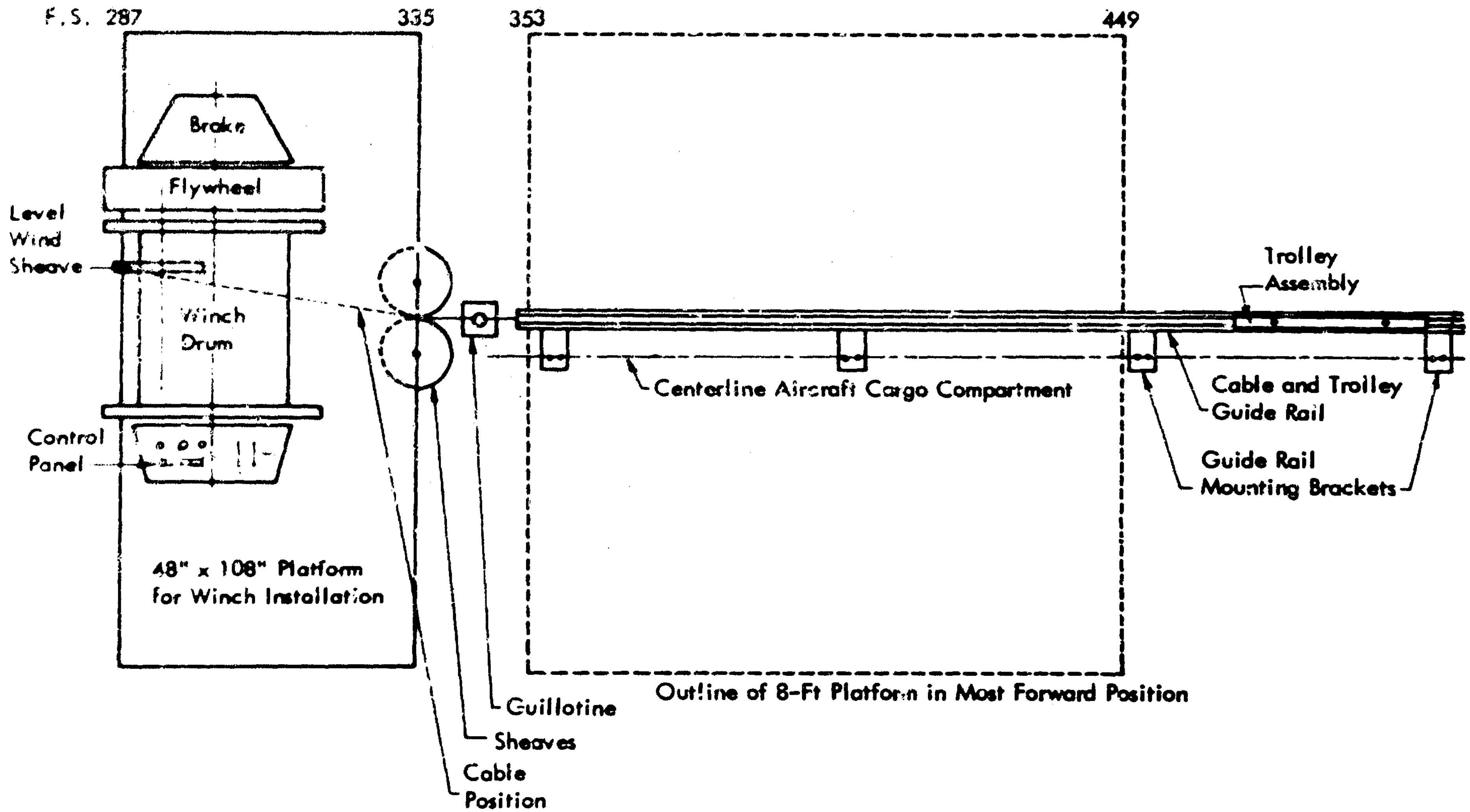


Figure - Schematic - Trolley Airdrop System (Top View)

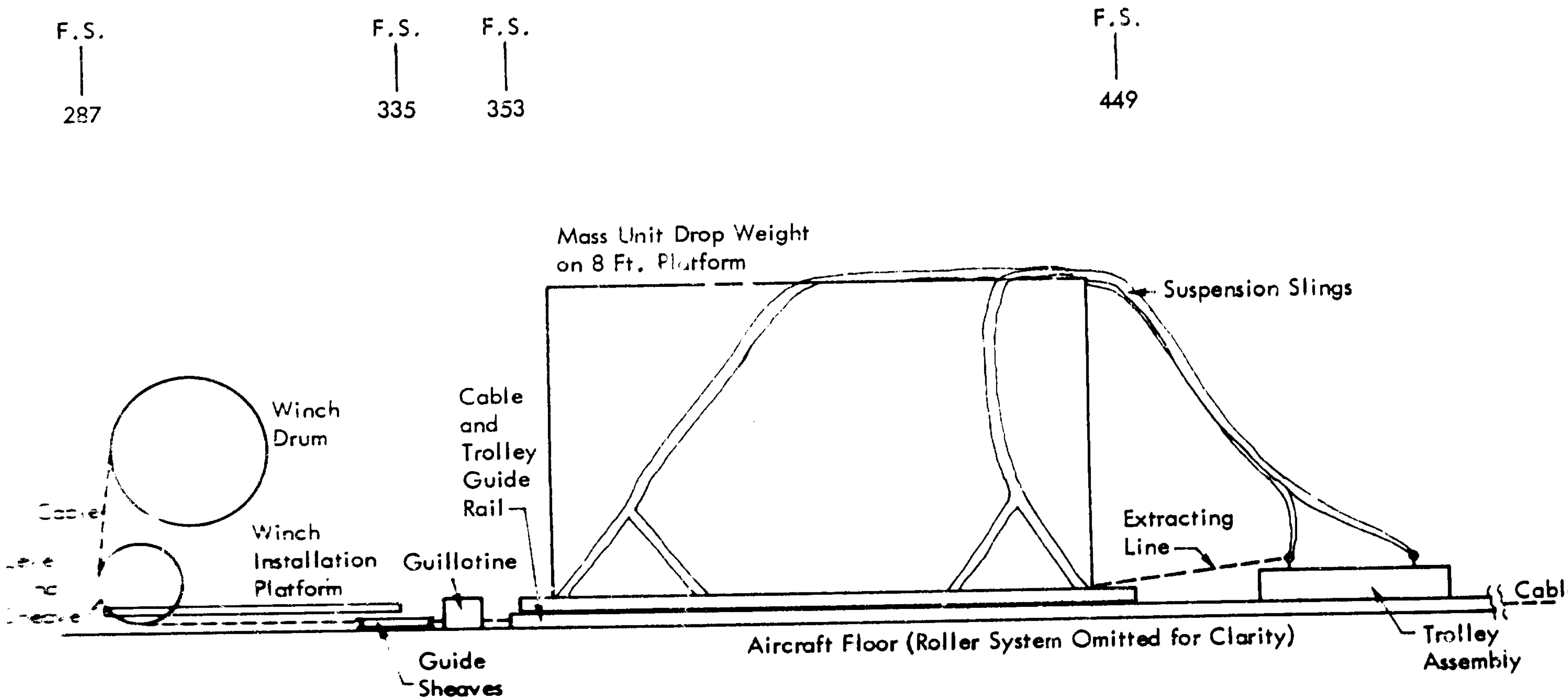


Figure 39 - Schematic - Trolley Airdrop System (Side View)

Parachute	Drop Cargo (Pounds)	Aircraft Velocity (Knots - EAS) 110	120	130	140	150
22 Ft. Diameter Ring-Slot		Reefing Line Length (Reefed Parachute Circumference - In.)				
	2,000	282	242	216	193	175
	4,000	489	432	384	342	300
	6,000	-	-	-	465	423
28 Ft. Diameter Ring-Slot						
	2,000	253	222	-	-	-
	4,000	446	382	340	322	-
	6,000	609	536	470	432	370
	8,000	-	-	584	533	470
	10,000	-	-	-	-	554
35 Ft. Diameter Ring-Slot						
	2,000	-	-	-	-	-
	4,000	383	337	297	264	-
	6,000	541	463	403	360	319
	8,000	680	586	515	456	409
	10,000	795	696	616	561	488

Maximum Opening of Fully Inflated Canopy $\frac{D_R}{D_O} = .625$

	22 Foot	28 Foot	35 Foot
Diameter (ft)	13.75	17.5	21.9
Circumference (inches)	519	660	825

Note: Although parachutes may be reefed down to 10 percent of full canopy ($\frac{D_R}{D_0} = .10$), the above entries do not include parachutes reefed below 20 percent of original opening ($\frac{D_R}{D_0} = .20$). Dash entries for various payload/airspeed for specific parachute indicate either (1) fully inflated canopy could not produce sufficient drag to accomplish 2.0 g extraction, or (2) parachute reefing required would be less than 20 percent ($\frac{D_R}{D_0} = .20$) of fully inflated canopy. Cable drag is not considered in the above calculations for reefed parachutes.

[illegible] 11 - Parachute Reefing Line Length Requirement for 2.0 g Drop Cargo Extraction Acceleration

Radar Altimeter - The function of the radar altimeter is to provide real-time absolute altitude information during airdrop. Current state-of-the-art radar altimeter specifications call for an accuracy of $\pm$ 2 feet or $\pm$ 2 percent of indicated altitude for zero to 2500 feet with 600 foot-per-second tracking rate. Two radar altimeters manufactured by Canadian Marconi Company (CMA-521) and Litton Industries, Inc. (ID No. 51788-3) are presently undergoing flight test and evaluation at the Lockheed-Georgia Company. These absolute altitude data from radar altimeters are essential to the Trolley airdrop concept because the system requires accuracy in this range to function properly. The accuracy of the APN-22 and APN-150 radar altimeters presently installed in C-130 aircraft are inadequate. Therefore, a retrofit program to install a radar altimeter similar to the two mentioned above is required.

Dual-Rail Cargo Handling System - The dual-rail cargo handling system and modular platforms persently utilized in C-130 aircraft perform the same function when used with the Trolley system. A maximum unit drop weight of 10,000 pounds with a 2 g-extraction can be airdropped with the Trolley system. No changes are required to T.O. 1-C-130A-9 regarding maximum drop cargo length, width, height, or center of gravity limitations. Some minor changes to Table 4A-2 and 4B-2, "Right Hand Detent Latch Settings" are required and loading procedures with the Trolley system winch will be established in a hardware development program.

Sighting Device - Although not required by the Trolley concept, the function of the sighting device is to improve accuracy by indicating to the pilot the time to release airdrop loads. The two sighting devices used by TAC C-130 aircrews for Parachute Low Altitude Delivery (PLADS) with a 60-degree sighting (depression) angle and an adjustable 10-degree azmuth angle are suitable for use with the Trolley system.

Rigging and Loading

Analysis of Trolley concept requirements for preparation of rigging of platforms and drop cargo indicate the following may be accomplished:

Deletions	Additions
o Honeycomb as energy dissipator	o Four cargo slings per unit
o Adhesive for honeycomb	o Second extraction line
o Extraction parachute for each drop cargo unit	

- Cargo parachute(s) and parachute platform for each drop cargo
- Parachute riser extensions
- Extra cargo parachute release (with multiple cargo parachutes)

The honeycomb as an energy dissipator may be eliminated due to low vertical impact velocity attainable (maximum 9.5 feet per second). Elimination of honeycomb will lower the vertical center of gravity location 3 to 9 inches depending on the cargo to be airdropped. This will decrease any tendency for the cargo to upset upon ground impact.

Individual extraction and cargo parachutes are eliminated since their function is performed by the Trolley system.

Table III shows 10 of the 15 loads selected by the TIE contractor which can be air dropped by Trolley using a C-130. The major reduction in Trolley system rigged weight is achieved by the deletion of the extraction and cargo parachutes and the plywood platforms. The reduction in rigging weights for Trolley varies from 177 to 972 pounds and represents from 32 to 83 percent reduction in rigging weight. Detailed listings of items deleted, including weight and cost, were furnished under separate cover to the TIE contractor. (See Appendix II).

For airdropping with the Trolley concept, the platform is prepared according to T. O. 13C7-1-5/TM 10-500. Elimination of honeycomb, extraction and cargo parachutes, and some plywood platforms requires repositioning of vehicles and recomputation of the modular platform centers of gravity. Lashing procedures for individual vehicle and mass loads remain basically the same as outlined in applicable Army TM's 10-500. Static lines similar to those employed for extraction and cargo parachutes with current airdrop systems remain the same for Trolley. Use of time delay cartridges (approximately 10 seconds) with the cargo parachute release is continued. Dual extraction lines attached to the slide assembly suspension points are utilized to prevent exceeding the limit load capacity of 1.5 times the rigged gross weight. Attachment of dual extraction lines is made to the front lifting shackles on vehicles such as the M151, 1/4-ton utility truck. For vehicles which do not have two shackles, the dual extraction lines are attached to the two attaching point extensions as shown in TM 10-500-10 for the M170, 1/4-ton ambulance. The capacity of the airdrop cargo suspension slings is doubled by the use of two slings per suspension point or by increasing the number of loops per sling. The load on the suspension point of the vehicle platform does not exceed the design load specified in MIL-STD-814A.

The analysis of platform travel from extraction to ground impact reveals that the platform experiences no rotation or reorientation

No.	Payload Nomenclature	Weight (Pounds)	Current Rigged Weight (Pounds)	Net Rigging Weight (Pounds)	Trolley Rigged Weight (Pounds)	Weight Saved (Pounds)	Weight Saved (%)
1.	M38A1	2956	4180	1224	3530	650	52.4
2.	M37	5687	7409	1722	6671	73[illegible]	42.8
3.	Mass Load	7000	8860	1360	8255	605	32.6
4.	M[illegible]	3840	5030	1190	4415	615	51.8
5.	M[illegible]	328[illegible]	4400	1113	3744	656	58.1
6.	[illegible]	[illegible]036	8626	1590	7654	972	61.1
7.	[illegible]74	5280	7160	1880	6368	792	42.1
8.	M151	2400	3088	688	2747	341	49.5
9.	M416	1870	2520	650	2196	324	49.3
15.	Mass Load	1750	1962	212	1785	177	83.5

Note: The above 10 loads were included in a list of 15 typical loads by Technical Integration and Evaluation (TIE) contractor. The above loads can be airdropped from C-130 with the Trolley system.

Table III- Rigged Weight of Selected Loads

around its vertical axis when suspended below the cable if proper rigging and sling attachments are followed. Offsetting the guide rail from the center of the cargo compartment ensures that platform movement during extraction from a position above to a position below the cable is uniform for each air drop. Studies of models of rigged cargo loads indicate that improper sling attachment to the slide can result in a 360-degree rotation of the drop load about the vertical axis after it clears the aircraft or can result in 180 degrees of rotation about that axis in either direction. This result is different from that reported in the informal progress report on this contract for the month of June 1966. In that report it was stated that rotation would occur; further analysis has shown that it need not occur.

Elimination of individual extraction and cargo parachutes, honeycomb, and plywood greatly reduces the unit drop weight cost per pound of cargo delivered, parachute inventory, unit rigging time, and the number of parachute-rigger and aerial port squadron personnel. A loadmaster assistant is required for multiple-pass/single-drop missions for duties similar to those performed during current PLADS and LAPES air drops per AFM 55-130. The overall skill level required remains the same. The number of parachute rigger personnel is reduced and loadmaster personnel requirements are increased for multiple-pass/single drops. Aircrew personnel (pilot, copilot and navigator) require no additional formal training.

Aircraft Operating Procedures

Single and Formation Airdrops - Airdrop with the Trolley concept in the C-130 can be made as follows:

- Single-pass/single-drop
- Multiple-pass/single-drop
- In-trail formation
- "V" in-trail formation elements

For "V" in-trail formation airdrops, some revisions and changes in procedure are required to AFM 55-130. It is necessary to eliminate the requirement for each element within a section to stack 100 feet above the preceding element. This change is required because accurate altitude control was found to be very important in the random error analysis. The only other change will be that the distance between elements is increased from 1000 to 2000 feet to ensure clearance between the towed parachute and succeeding aircraft.

For in-trail formation it is desirable to reduce spacing to 6000 feet between element leaders (in lieu of 2-mile spacing), propwash

permitting.

Multiple-pass/single-drop missions are accomplished by a single aircraft flying a rectangular pattern at 120 knots with 3-minute up-wind and down-wind legs, 1-minute cross-wind legs, and a 15-degree bank in the turns as shown in Figure 40. A nominal time of 10 minutes is required to fly this rectangular pattern. A 6-minute check can be accomplished before airdrop upon entry to the down-wind leg. The Computed Air Release Point (CARP) is located approximately 1 minute after entry to the up-wind leg. This rectangular pattern could be adapted to in-trail and "V" in-trail formation airdrops. Single-pass/multiple-drop (air assault) procedures and techniques have not been developed for Trolley.

Combination equipment/personnel airdrops are not compatible due to conflicting altitude requirements. Trolley's airdrop altitude for cargo varies from 440 to 530 feet. Current drop altitudes for personnel, as listed in AFM 55-130, are as follows:

o Personnel on tactical training	1000 feet
o Personnel in combat	750 feet
o Personnel during wartime training	900 feet
o Basic airborne students	1250 feet

If it is assumed that personnel drops can be made at 500 feet, then it is possible to make equipment/personnel drops concurrently as is discussed on page 161 of this document.

Terrain and Drop Zone Clearance Requirement - The Trolley concept's airdrop altitude for cargo varies from 440 to 530 feet. The cable, when deployed 1300 feet, trails behind the aircraft in a vertical plane with the end of the cable about 118 feet below the aircraft as shown in Figure 41. The parachute at the end of the cable maintains a position at least 300 feet above the terrain until the winch brake is released over CARP.

Airdrop during a 15-knot direct cross wind requires an aircraft drift correction of approximately 8 degrees for an aircraft speed of 110 knots. Other cross wind/airspeed drift correction angles are shown in Table IV. Thus, the parachute ground track is parallel to the aircraft ground track and is displaced a maximum of 178 feet downwind from the aircraft ground track when the aircraft is flying at 110 knots. The drift vector is compensated for during the calculation of the CARP.

Single Ship - 10 Min to Complete Pattern for Second Pass

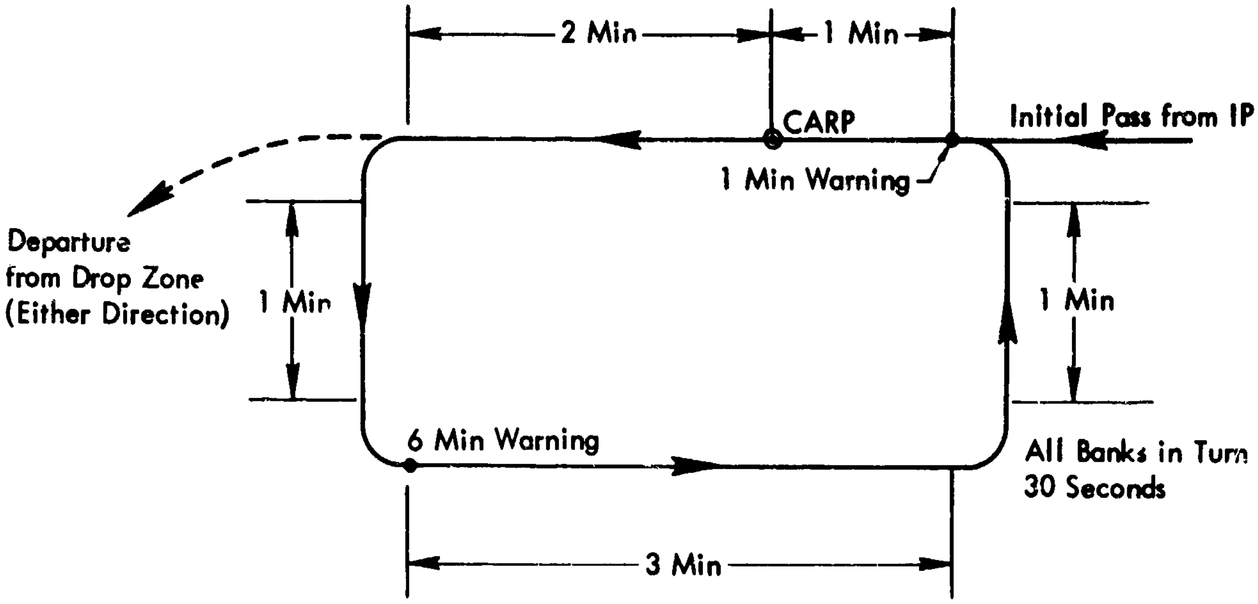


Figure 40- Rectangular Pattern for Multiple Pass/Single Drop

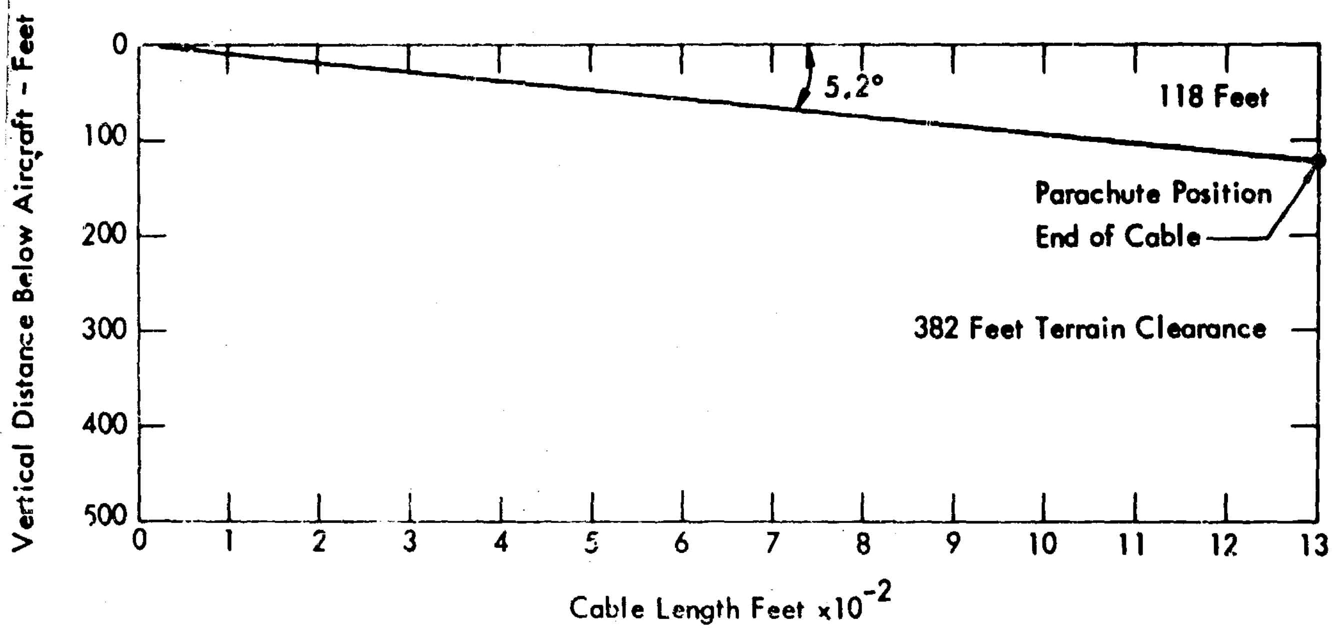


Figure 4 - Cable Depression Below Aircraft

Aircraft Speed - Knots	Angle Between Airplane Ground Track and Cable - Degrees	Parachute Displacement from Airplane Ground Track - Feet
110	7.8	177
120	7.1	163
130	6.6	150
140	6.1	139
150	5.7	130

Table [illegible] - Cable Lateral Displacement for 15 Knot Crosswind (1300 Foot Cable Length)

The heavier drop cargos have the most shallow trajectories and require a cleared 200-foot horizontal distance prior to ground impact to clear a 50 foot obstacle. For single-pass/single-drop, the accuracy analysis indicates that airdrops with the Trolley concept can be contained within an ellipse having a semi-major axis of about 90 feet parallel to the flight path and a semi-minor axis of about 9 feet normal to the flight path.

With 30 aircraft flying a "V" in-trail formation, a drop zone about 1800 feet long and 305 feet wide is required to allow airdrop from each aircraft without interference. The length of the drop zone is determined by adding the maximum longitudinal miss distance (± 90 feet) for each element of three aircraft in the formation. The lateral distance is determined by center-to-center spacing requirements of the aircraft and not by the maximum lateral miss-distance for Trolley airdrop. Accuracy analyses of Trolley airdrop indicate that if accurate wind prediction at drop altitude can be accomplished, then Trolley can deliver a piece of equipment on a straight road within 90 feet (longitudinal distance) of a selected point. The Trolley drop zone size is well within the present requirement for 1800 by 1800 feet for one parachutist, 1800 by 3000 feet for one heavy equipment platform, and 2100 by 3000 feet for three aircraft in "V" formation.

The 1200-foot requirement added to the drop zone length for each succeeding platform in AFM 55-130 requires revision to take Trolley system accuracy into consideration. Such consideration is given to

other systems as shown by the 60 by 60-foot clearing for PLADS and the 2000 by 150-foot clearing for LAPES and GPES.

Adverse Weather Operation - Since Trolley is composed of relatively simple mechanical components, there should be no major problems involved in designing it to operate under adverse weather conditions. Design requirements for operational considerations such as sand and dust, extreme temperatures, rain, fungus, etc., will be included in the early design work.

Air drops by Trolley under adverse weather conditions will be limited by such things as aircraft navigational problems rather than by the ability of the Trolley equipment to operate. This limitation is the same as presently experienced by operational systems and is not further aggravated by Trolley. Air drops at night will pose no particular problems if suitable visual or electronic contact with the drop zone is established.

Operational Check List - Trolley procedures are similar to those used on present C-130 aircraft with a 20-minute warning, 10-minute warning, 6-minute warning, 1-minute warning, arrival at the CARP (green light) and completion of drop (red light). These procedures remain in effect with minor changes, outlined below, in aircrew duties and responsibilities from those used in AFM 55-130.

- 20-Minute Warning

  Delete: 4. Remove the parachute tiedown straps which may have been installed to hold the main parachutes in position on the loads.

- 10-Minute Warning

  No change

- 6-Minute Warning

  Add: 8. To Loadmaster Duties: Arm winch control panel to release pendulum drag chute and 1300 feet of cable when ADS button is depressed by the right-seat pilot. Return to position at station 245 and notify pilot "6-minute checks complete."

  Add: 9. To Pilot Duties: The right-seat pilot will upon receipt of notice from Loadmaster "6-minute check complete" actuate the ADS button deploying the drag chute and extracting 1300 feet of cable off the winch drum.

  Add: 10. To Loadmaster Duties: After checking indicator on control panel that 1300 feet of cable have been deployed,

he will press control override button (preventing early platform release) and fasten the tapered stop on the cable next to the Trolley assembly, return to his position at station 245, set calibrated control panel for weight (2000, 4000 pounds, etc.) to be airdropped, and notify pilot that the load is ready.

- 1-Minute Warning

  No additions. Some items normally accomplished during one-minute warning were accomplished in 6-minute warning check.

- Arrival at CARP (green light)

  Change in Pilot Duties: The pilot in right seat will simultaneously turn the green light on and depress button releasing winch brake, thereby extracting payload and automatic reel-out, braking and reel-in of cable until ground impact of drop cargo some 12 seconds later.

- Completion of Drop (red light)

  Add to Loadmaster Duties: Place drogue on cable and let drogue slide down cable toward parachute until parachute canopy is collapsed (streamer). Operate winch control panel and retrieve parachute by reel-in of deployed cable. Notify pilot when clear to close the ramp and door.

  Note: For additional drops Loadmaster will reel-in cable with drag parachute to 1300-foot position and place Trolley assembly into cable and Trolley guide with extraction line and cargo slings attached if not already in position. Checks will be initiated starting with 6-minute warning. Pilot will fly rectangular pattern shown in Figure 40.

Trolley System Compatibility with Other Aircraft

The Trolley system has been analyzed and designed for installation in a C-130 aircraft. However, some consideration was also given to the installation of this system into the C-141, CV-2, and CV-7 aircraft. In general, the results of this consideration showed that no particular problems would be encountered in utilizing the system in these other aircraft.

Compatibility with C-141A - The Trolley system can be adapted for airdrop of equipment from the C-141A. Figure 42 presents the amount of excess thrust available at 220,000 pounds of gross weight in standard atmosphere at sea level and at a 5000-foot altitude. The

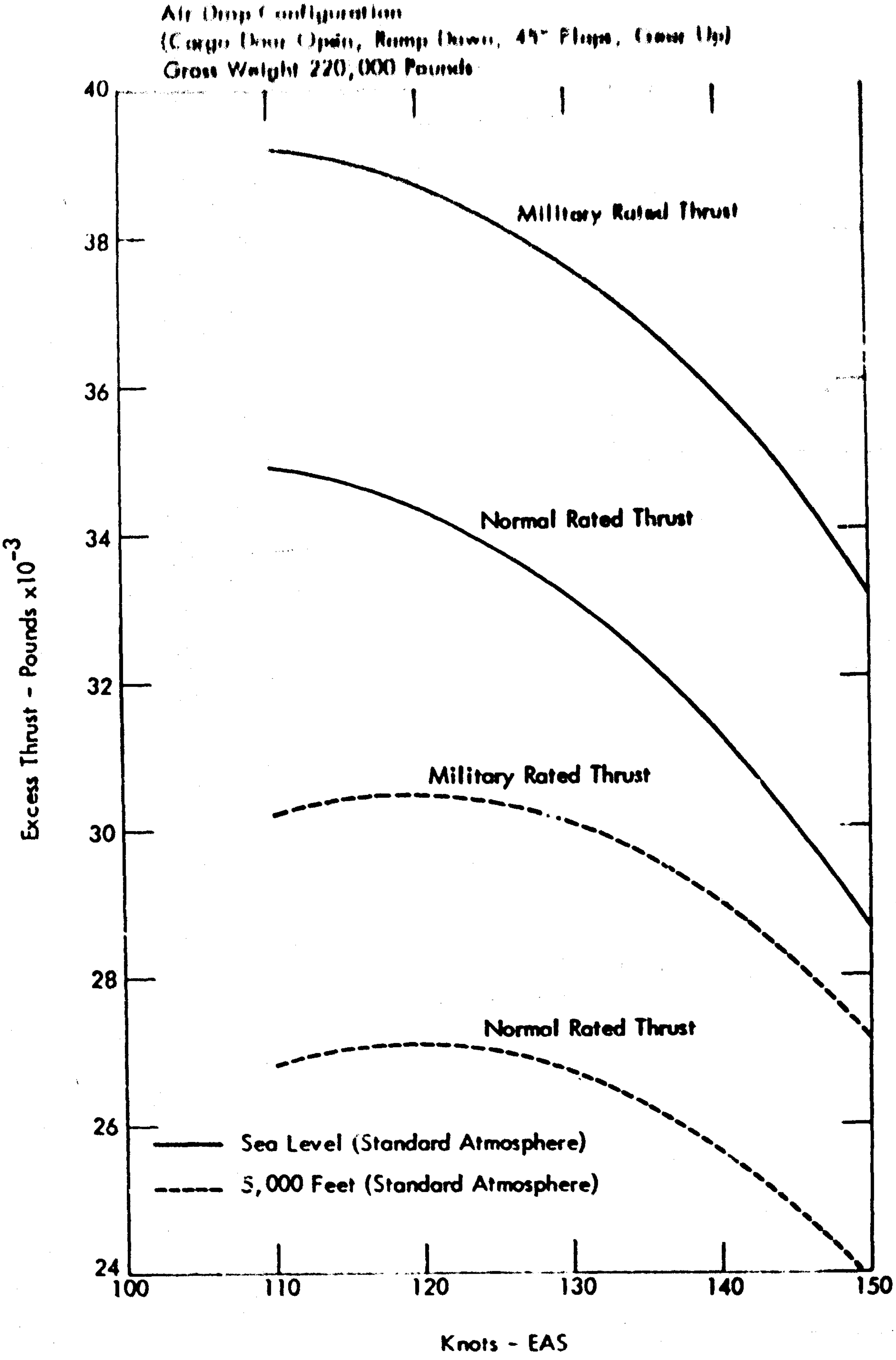


Figure ... - C-141 Excess Thrust Available at 220,000 Pounds Gross Weight

weight which can be airdropped with the Trolley concept is one-half of the excess thrust available. Thus, the C-141A can airdrop weights of 20,000 pounds at sea level and 16,000 pounds at 5000-foot altitude drop zones. Of the 15 typical loads identified by TIE contractor, only the ARAAV (Load No. 14) cannot be airdropped with the Trolley system. The 19,000-pound M113 armored troop carrier with less rigging weight can be air dropped at reduced aircraft gross weight.

The 9 x 10 x 70-foot cargo compartment of the C-141A is similar to the C-130 cargo compartment and has a compatible integral rail system.

For the 20,000-pound airdrop capability, a slightly larger winch and cable diameter is required. The cable tension loads are doubled and a 1-1/8-inch diameter cable is required. The Trolley equipment with the 2000 to 10,000-pound air drop capability for the C-130 could also be utilized in the C-141A.

<u>Compatibility with CV-7A and CV-2</u> - Based on available data, Figure 47 presents the CV-7A aircraft excess thrust available at the 30,000-pound gross weight at sea level, standard atmosphere and at 5000 feet (85°F) in clean configuration (ramp up, door closed). The airspeed range is increased in scope to include the normal 80 to 110-knot airdrop speed of the CV-7A. At the slower 80-knot airspeed, a 4000-pound unit weight can be airdropped at sea level. The unit weight capability is reduced since the aircraft gross weight, including Trolley system, payload, and fuel, is 32,000 to 34,000 pounds with additional drag produced by the ramp and cargo door during airdrop thereby reducing excess thrust shown in Figure 47. The unit weight which can be air dropped at a 5000-foot altitude (hot day) is approximately 2200 pounds at the same aircraft gross weight.

The capability for CV-2 aircraft cannot be determined due to non-availability of detailed aircraft performance data (power available versus power required) which was requested from the U. S. Army. Comparison of normal CV-2 and CV-7 payload-carrying capability, 7103 pounds for CV-2 versus 11,665 for CV-7, indicates that the CV-2 has a limited capability. Installation of the Trolley system reduces the amount of payload which can be carried. CV-2 operation at or near maximum gross weight is required, thus reducing the amount of excess thrust available for airdrop with the Trolley concept.

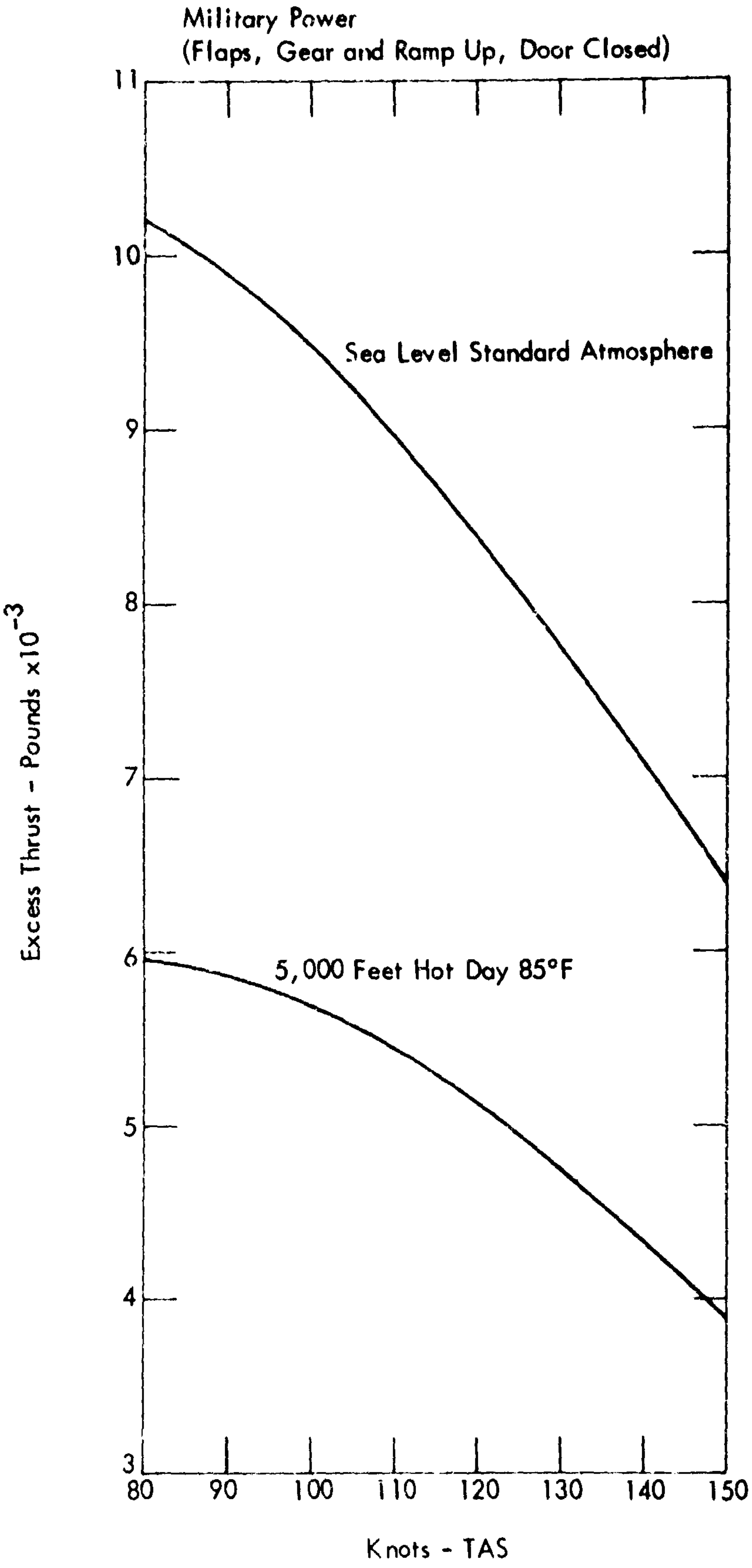


Figure 43- CV-7A Excess Thrust Available at 30,000 Pounds Gross Weight

FUNCTIONAL ANALYSIS

The functional analysis of the Trolley system consisted of investigation of the following items:

- Mechanical Reliability
- Maintainability
- Simplicity
- Safety
- Economy

Each of these items is considered important to the overall evaluation of the system's true value to the user. A discussion of each follows.

Mechanical Reliability

A reliability analysis of the Trolley system, conducted to assess the reliability level inherent in the proposed conceptual design, is based on one complete operation of the system with the delivery of a single drop cargo to a pre-selected drop zone. A failure is defined to be any malfunction which results in failure to deliver the payload in a usable condition. A reliability level of 0.9997 is predicted for the proposed Trolley system based on the above ground rules. This prediction includes equipment presently installed in the C-130 aircraft which is specifically utilized during Trolley airdrop operation but is not peculiar to the Trolley system. It is assumed, however, that all other airborne equipment will function properly during the airdrop operation.

Predicted reliability values for individual equipment are shown in Table V. These values are based on experience with similar components from 27,832 flights hours of C-141 operational data; data from HC-130H test programs; and engineering judgment.

The high reliability level predicted for the Trolley system can be attributed to the short duration of the airdrop operation and to the fact that the system is composed primarily of mechanical equipment which has historically demonstrated high levels of reliability. The system does, however, contain hardware which is not available "off-the-shelf." Further development of this equipment must ensure that good reliability design practices are adhered to if a high level of reliability for the system is to be achieved.

Nomenclature	Failures/10^6 System Operations	Predicted Reliability
Winch	200	0.9998
Winch Control	20	0.99998
Cable	1	0.999999
Trolley Slide Assembly*	3	0.999997
Cable & Trolley Guide Rail	1	0.999999
Drag Parachute	1	0.999999
Cargo Tiedowns, Slings, and Extraction Lines	3	0.999997
Pendulum System	48	0.999952
Sighting Device	1	0.999999

*Includes functional redundancy

Table V - Mechanical Reliability Predicted Values

The reliability analysis indicates that the winch is potentially the primary reliability problem area in the system. In general, experience with winches in aircraft applications such as the HC-130H program indicates that the principal problems are created by the fact that winches are predominantly designed for industrial applications. Thus, the problems associated with the high-strength, light-weight requirements of aircraft applications are frequently neglected even with winches designed to aircraft specifications. Experience has also shown that this general problem can be overcome by adequate reliability monitoring and control during winch design and development.

More specific reliability problems are expected to arise from the braking and reel-in rate requirements. Although landing gear braking hardware (such as that found on B-52 aircraft) can be used for braking the winch, the reliability state-of-the-art for such systems has been unsatisfactory, historically. This potential problem area has been

lessened somewhat since it was found that increased braking times (from 0.5 to 1.5 seconds) are permissible within the operational concept of the system. The reel-in rate requirement against the expected tensile loads imposes an unusually high-power requirement for the winch. This requirement, as well as other considerations, makes the use of a direct electrical or hydraulic drive for the winch very difficult. Use of a flywheel to store energy until reel-in is required would preclude the requirement to add an electric or hydraulic power source to the aircraft system to power the winch. This simplification will make the winch reliability goals easier to meet.

The winch control panel is not expected to be a reliability problem due to its relative simplicity. It is assumed that the control panel will consist of a simple timing device and associated control equipment and will not include more sophisticated capability such as cable tension sensing devices or automated input of aircraft flight parameters.

The Trolley slide assembly is expected to be highly reliable due to the basic simplicity of the assembly and functional redundancy in the drop cargo relase mechanism.

The remaining hardware peculiar to the Trolley system is essentially mechanical in nature. Employment of standard reliability practices, such as derating and the use of high-reliability parts will ensure a high inherent level of reliability for these parts.

Maintainability

Ease of maintenance has been a prime consideration in the conceptual design of all Trolley equipment. Efforts have been made to choose equipment which will operate in a military environment with a minimum of servicing. It is expected that this emphasis on maintainability will result in reduced operating costs of the Trolley concept.

All equipment installed in the drop aircraft is exposed and immediately accessible. There are no covers over the trolley guide rail on the aircraft floor or over the winch. Suitable safety guards on the winch can be quickly opened should the need arise.

Since component weight is not extremely critical, this consideration aids in assuring that each part of the system is rugged and designed for long life. This approach improves maintainability since the results of poor care and rough usage can be tolerated better by rugged components.

The Trolley system has no highly complex equipment which requires servicing by highly skilled technicians. The only possible exceptions

are the winch and the winch control. These units are simplified as much as possible to ensure that personnel in the field can maintain and operate each item.

An analysis of each of the major components of the Trolley system serves to illustrate its ease of maintenance.

- Winch - Built to standard manufacturing practices, this winch is within the state of the art. Periodic inspection and lubrication are the only maintenance items expected. The winch is mounted in the forward end of the cargo compartment and is accessable from all sides. Standard winch drive and cable level wind mechanisms are designed so that standard hand tools can be used on them.

- Winch Control - The winch control is basically a simple timer mechanism with an element to control cable tension and brake pressure. The unit is relatively unsophisticated and can be repaired in a standard instrument shop. Field adjustments and module replacement are also possible. The control is mounted on the winch where it is easily accessable.

- Cable - A standard 18 x 7, or special 19 x 7, swaged cable will be used. Periodic inspection and lubrication are the only maintenance items expected.

- Trolley Slide Assembly - Inspection of the teflon liner for damage and thickness is the only expected maintenance item prior to reuse.

- Guide Rail - Completely exposed with no moving parts, little or no maintenance is expected.

- Drag Chute - Normal inspection, repair, and repacking presently done on other parachutes are the only maintenance items anticipated.

- Tiedowns - Maintenance will consist of inspection and repair as done on present airdrop rigging.

- Sighting Device - Little or no maintenance is expected.

From the information presented above, it can be seen that the use of standard equipment which have few moving parts and which are easily accessable makes Trolley a system which can be easily maintained in the field.

Simplicity

To the extent possible within the scope of this study contract, the simplicity of the Trolley system and its components was considered a very important factor. Efforts were expended in an attempt to make the system as uncomplicated as possible so that it would have higher inherent reliability, be easier to operate and maintain in the field, and have a lower cost for acquisition and operation.

As presented in the original proposal*, the trolley which slides down the cable (from which the payload is suspended) was a relatively complicated and rather costly wheeled mechanism. A mathematical evaluation was conducted to determine if a slide could be substituted for the wheeled trolley. Of prime concern was the sliding efficiency or coefficient of friction of such a slide, the heat build up involved, effects of the sliding and heat on the materials involved, and availability of appropriate materials. Results of this investigation show that a slide lined with teflon has little or no heat build up, has a sliding friction only slightly higher than the wheeled trolley, and can be fabricated much more economically. Thus, present plans are based on replacing the wheeled trolley with a slide.

Further attempts at simplification of the trolley slide will be made during the hardware development phase of the Trolley concept. A slide manufactured economically enough to make it feasible to discard it after each use would further simplify the maintenance and operation of the system.

Efforts were expended to reduce the aircraft modifications and complexity of the drop sequence resulting from routing the tow cable along the ceiling of the cargo compartment. The result of this effort is a system which routes the cable in a guide rail under the drop platforms between the platforms and the aircraft floor. This system eliminates many of the cable guides and pulleys and makes multiple drops from the same aircraft possible.

A further simplification is the decision that the control for the winch need not have the ability to sense cable tension and then adjust reel-in rate in order to keep a constant line tension during reel-in. Instead, a clutch mechanism is installed on the winch drive which runs at a constant torque, thus giving constant line tension.

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*Lockheed-Georgia Company. A proposal for a Preliminary Investigation of the Trolley Low-Altitude Airdrop Concept, ETP 635. July 1965.

The winch control was also changed so that is need not sense the length of cable payed out to determine when the brake should be applied to stop the winch. Instead, a simple timer, set to the same values for all loads, is used to initiate braking and winch reel-in. These changes to the winch control greatly simplify its operation.

When Trolley is compared with the present airdrop systems, it can be seen that the elimination of recovery parachutes and their packing and rigging and elimination of the honeycomb decelerators make Trolley much simpler to operate. The ability to drive vehicles onto the airdrop platforms for rigging and to drive them off after drop saves much time, exposes the combat soldier to enemy fire for a shorter time while getting the vehicle into combat, and eliminates the need for large fork lifts and cranes for loading and unloading. This simplification makes total system operation cheaper and releases more men for combat.

In summary, it is seen that the reduced number of components, shorter rigging and derigging time, and lack of residue on the drop zone makes Trolley cimpler than present systems to operate and maintain.

Safety

A safety analysis of the Trolley airdrop concept has been conducted by Aerospace Safety Engineers to determine the adequacy of control, warning and protective devices, normal and emergency operating procedures, and check lists. Based on the following determinations, it is concluded that the Trolley concept, as proposed, poses no undue hazard to the safety of personnel, aircraft, or equipment.

The unit drop weight will be limited to less than 50 percent of the excess thrust available under existing conditions of altitude, temperature, airspeed, and gross weight for 2.0-g extraction.

The dual-rail cargo system with modular platforms, the drag parachute ejection pendulum system, and the sighting device to be used are not peculiar to the Trolley concept but are typical service-proven items presently installed on airdrop C-130 aircraft. They are attached to the aircraft in the conventional manner and pose no undue hazard to the aircraft.

On-board cable routing pulleys, guides, and guards provide adequate crew protection.

Standard airdrop/aircrew operational procedures, established by AFM 55-130, are followed except for the minor changes in aircrew duties and responsibilities peculiar to the Trolley concept. (Refer to

check list in Operational Analysis section.)

The winch installation and drive mechanism are enclosed for aircrew and airframe protection.

The minimum breaking stength of 3/4-inch, 18 x 7 wire rope is 47,960 pounds. Calculated cable tensions are as follows:

Steady line tension	20,000 Pounds
Peak line tension (at braking)	26,910 Pounds
Cable dynamic load factor	4,140 Pounds
Total cable tension (Peak load & Dynamic load)	31,050 Pounds
Design load (Total cable tension x 1.5 Safety factor)	46,575 Pounds

Winch design and requirements, though not finalized at this time, are within the state-of-the-art.

The cable and winch installation is grounded to aircraft structure to eliminate static electrical discharge hazard.

The loadmaster is provided with a headset and microphone with sufficient cord length to provide freedom of movement while he maintains continuous voice contact with the cockpit crew.

The initial shock load at drag parachute deployment and at braking is well below the cable and winch installation design load capability.

Winch and cable control for the load extraction, braking, reel-in sequence is mechanically programmed but has manual operation capability which allows remote operation by the copilot from the cockpit or by the loadmaster in the cargo compartment.

Load extraction from the aircraft is accomplished at 2 g-acceleration in 1.2 seconds, which minimizes aircraft response and possible interference.

Standard rigging procedures for various type loads are used to preclude load entanglement, and rigging for Trolley airdrop is simpier than rigging for normal airdrop.

On ground impact, a standard parachute release automatically releases the load from the trolley. As a backup safety item, a cargo release stop, located on the cable 10 feet from the parachute, mechanically separates the trolley and load from the cable in the event the impact

load release mechanism has not been activated or has malfunctioned.

In the event of a snagged chute or load, a slip-clutch mechanism incorporated in the winch assembly and adjusted to a cable tension horizontal component equal to 1.8 g, releases the total length of cable from the drum before the total drag reaches the excess thrust available under the existing conditions.

In the event of any emergency, an explosion-proof, electrically-excited, cartridge-actuated cable cutter, located adjacent to the winch and operated remotely by either the copilot or the loadmaster, provides the primary means of jettisoning the cable, load, and drag parachute at any time during the airdrop sequence. The loadmaster has the prerogative of disarming the cable cutter whenever he deems it necessary for personal safety when he is working in close proximity to the cable.

The Flight Test Program on drag parachute performance, completed in May 1966, indicates that the snap-back or whip, resulting from a cut or failed cable under tension, is negligible and does not jeopardize the safety of the air crew or aircraft.

In the event of a failure resulting in an inadvertent gravity airdrop, the results of the Lockheed-Georgia's, C-130E Inadvertent Gravity Airdrop Demonstration ER-7626, November 23, 1965, indicate that such airdrops were successfully performed at cargo weights of 19,940 pounds at 130 KEAS and 28,150 pounds at 150 KEAS. The 10,000 pound, 130 KEAS configuration proposed in the Trolley low-altitude airdrop concept is well below the demonstrated capabilities of the aircraft and aircrew.

All components of the system will be functionally tested and ground operated prior to flight.

Economy

Because of the unique nature of the Trolley airdrop concept, cost advantages accrue that allow the cost per-delivered-pound of airdrop items to be reduced. This accrual is due primarily to the following reasons

- Parachute is retrieved into the aircraft
- Less shock absorber material is required
- Rigging requirements are reduced
- Damage to items airdropped is minimized
- Improved accuracy reduces loss caused when the drop zone is missed

The initial cost of Trolley equipment as presented in Table VI can be amortized over the life of the system. All the items of Figure 49 stay with the aircraft or are retrieved into the aircraft after airdrop with the exception of the slide. The slide is reusable, but it is released from the cable after airdrop.

The cost* per airdrop of equipment peculiar to the Trolley concept is $20.24 based on a 10-year life with the aircraft's flying three missions per week and airdropping three items on each mission. This number was obtained by adding the estimated costs of all items in Table VI (except the slide) and dividing by the total number of times the system is utilized. The slide was not included because it is not retrieved into the aircraft even though it is reusable.

In the detailed rigging analysis conducted for the TIE contractor, it was determined that Trolley could save an average of about $2500 per load due to a reduction in parachutes, rigging, and shock absorbers. For example, a net saving of $2487.43 (based on not reusing the parachutes) was realized in rigging an M38A1 1/4-ton Utility Truck for Trolley airdrop as compared to conventional airdrop. By utilizing this number and subtracting the costs for Trolley equipment (based on not reusing the slide), a net saving of $0.51 per pound delivered is realized on this particular airdrop item. Similar savings are realized on other items of equipment that are airdropped.

It should be noted that the only item left on the ground other than rigging is the slide. Its cost is relatively small when it is considered that just one G-11A parachute costs $1150, and two or more of these parachutes are required to airdrop many items of equipment. Three G-12D parachutes for the above load cost $1746.

Another advantage gained in economy with Trolley is that less payload capability of the airplane is required since the Trolley rigged weight is generally about 30 percent less than that required for conventional airdrop. This weight savings permits increased range for the aircraft or allows operation at lower gross weights.

No attempt was made to calculate the savings resulting from the reduction in rigging and derigging manhours and the lower damage rate due to lower velocity and higher accuracy impacts. However, these savings are thought to be considerable.

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* Winch cost is assumed to be $84,000

Item Description	Quantity	Average Unit Cost Dollars	High Estimate Dollars	Low Estimate Dollars
Slide	1	600	1,000	400
Guide Rail	1	500	800	400
Stop	1	45	75	25
Guide Pulley	2	35	50	20
Cable	1	2,000	2,400	1,800
Guillotine	1	250	300	225
22' Ringslot Parachute*	1	250	300	235
28' Ringslot Parachute*	1	370	420	350
35' Ringslot Parachute*	1	500	550	480
Winch Platform	1	500	700	400
Radar Altimeter	1	7,000	7,800	6,800
Winch	1	84,000	84,000	84,000
Trolley Equipment Cost		95,335	97,595	94,440

Note: The winch concept is within the state of the art and would not require any breakthrough in technology. However, Lockheed has little experience in estimating winch costs and does not feel qualified to pass judgment on these figures; hence no estimate of high and low costs was made.

*Only one parachute used per drop. The 28-foot parachute costs were used in arriving at the totals.

Table VI- Cost of Peculiar Trolley Equipment

TEST PROGRAM

A flight test program was conducted in order to confirm that the trailing parachute is relatively stable and behaves in a predictable manner. Verification of mathematical predictions of parachute positions was a secondary objective. The tests consisted of towing a parachute on a cable at distances up to 2,000 feet behind a C-130 flying at speeds ranging from 110 to 150 knots. Certain laboratory tests were conducted prior to flight tests to ensure safety during the flight test. Laboratory tests were conducted at the Lockheed-Georgia Company and flight tests were conducted at the El Centro Naval Air Facility, California.

Laboratory Tests

In order to ensure safe operation of the cable cutters installed in the test equipment, it was decided to conduct a functional test of the cutters. The test was conducted utilizing the equipment shown in Figure 44. Cable specimens approximately 5 feet long were rigged using the same wire rope eyes which were used during the flight tests. One end of the cable was fixed to a pin and the other was attached to a load cell and hydraulic cylinder. Tension was applied to the cable by the hydraulic cylinder and the load on the cable was determined from instrumentation associated with the load cell. A schematic diagram of the test equipment is shown in Figure 45.

The test set-up was completed on 15 February 1966 and the six tests were run on 15, 16 and 17 February. Figure 46 shows the results of the cable cutter operation when a cable was severed by the cutter with no tension applied to the cable. The photograph shows that a clean cut was made. The cutter operated instantaneously and no noticeable shock or rebound occurred. This test was followed by one in which 5000 pounds of tension was placed on the cable prior to firing the cutter. Since this condition is considered the one which most closely simulates the operational tests, it was repeated twice. The results of both tests were identical as shown in Figure 47. Again, the cable was cut cleanly. Three tests with the cable under a tension of 10,000 pounds were conducted since this is the highest flight test load expected. Again, instantaneous cutting of the cable was clean, but the cable unraveled more than in the 5000-pound tension test. Results are seen in Figure 48. In all tests the cutter fired instantaneously with no flame or smoke. Figure 49 shows the disassembled cable cutter used in these tests. The same cutting chisel was used for all tests with little or no erosion occurring. Figure 50 shows the anvil used in the cutter. Although the vendor considers these anvils to be expendable after each test, it is seen that multiple firings on the same anvil

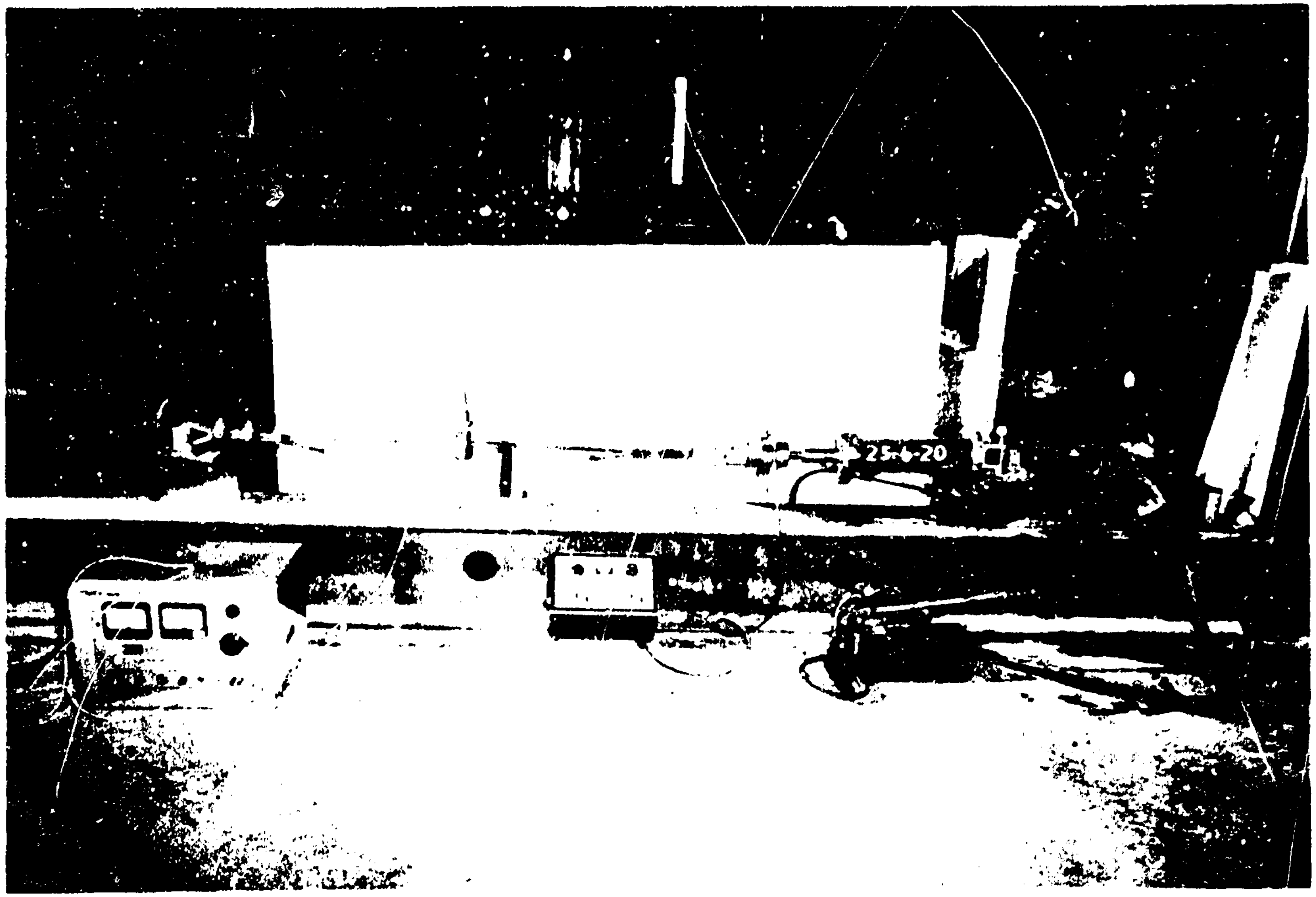

Figure 44 - Laboratory Test Equipment

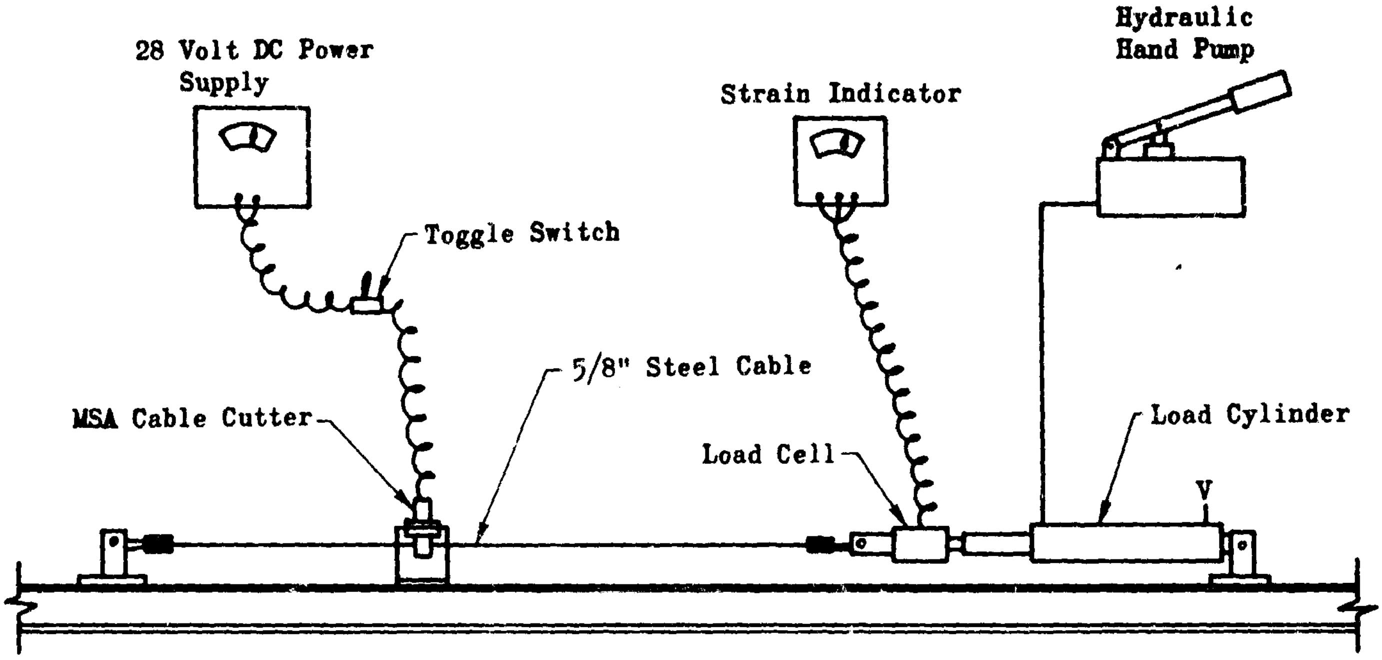

Figure 45 - Schematic - Laboratory Test Equipment

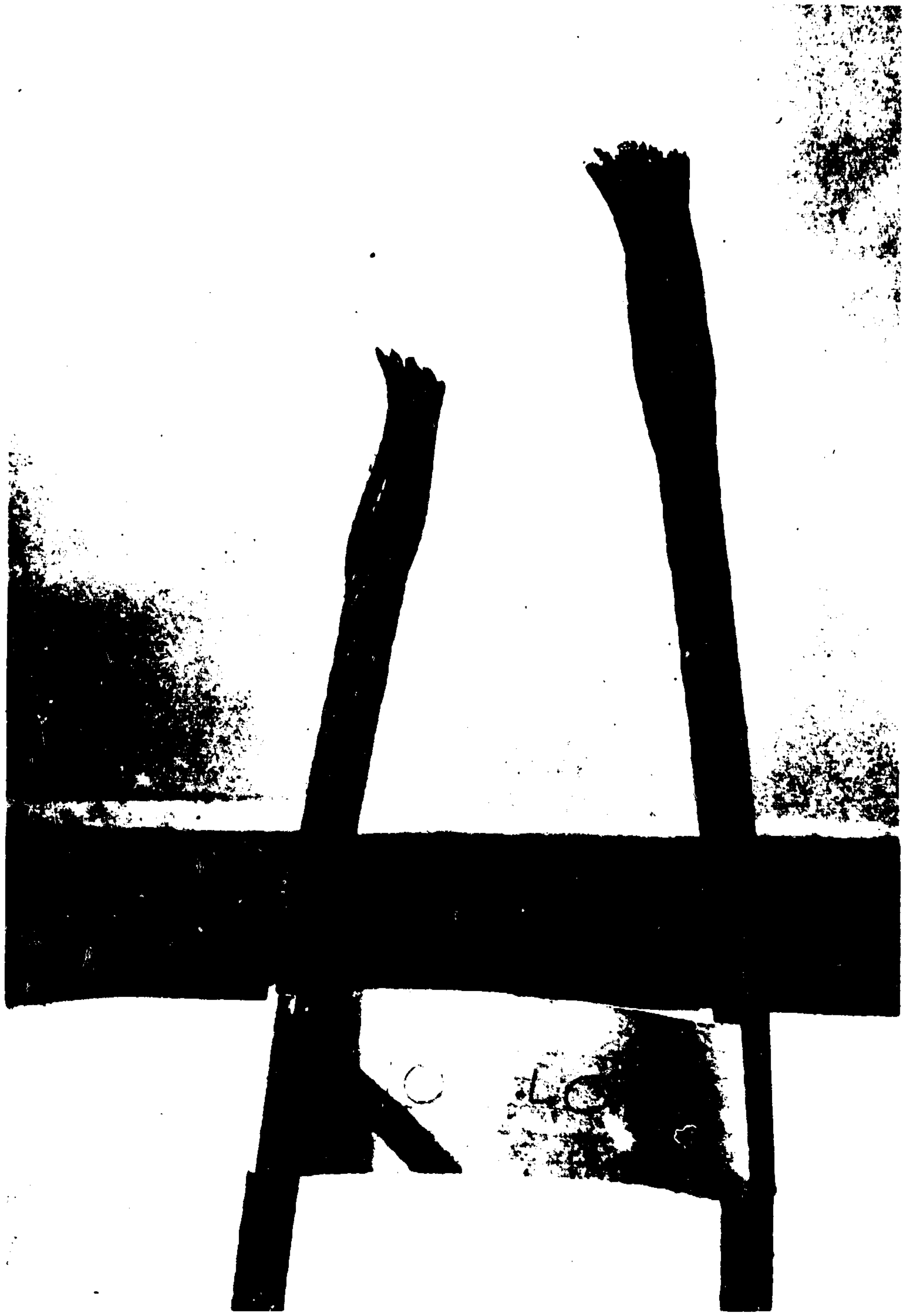

Figure 46 - Laboratory Test Results -- Cable under No Tension

Figure 47 - Laboratory Test Results -- Cable under 5000-Pound Tension

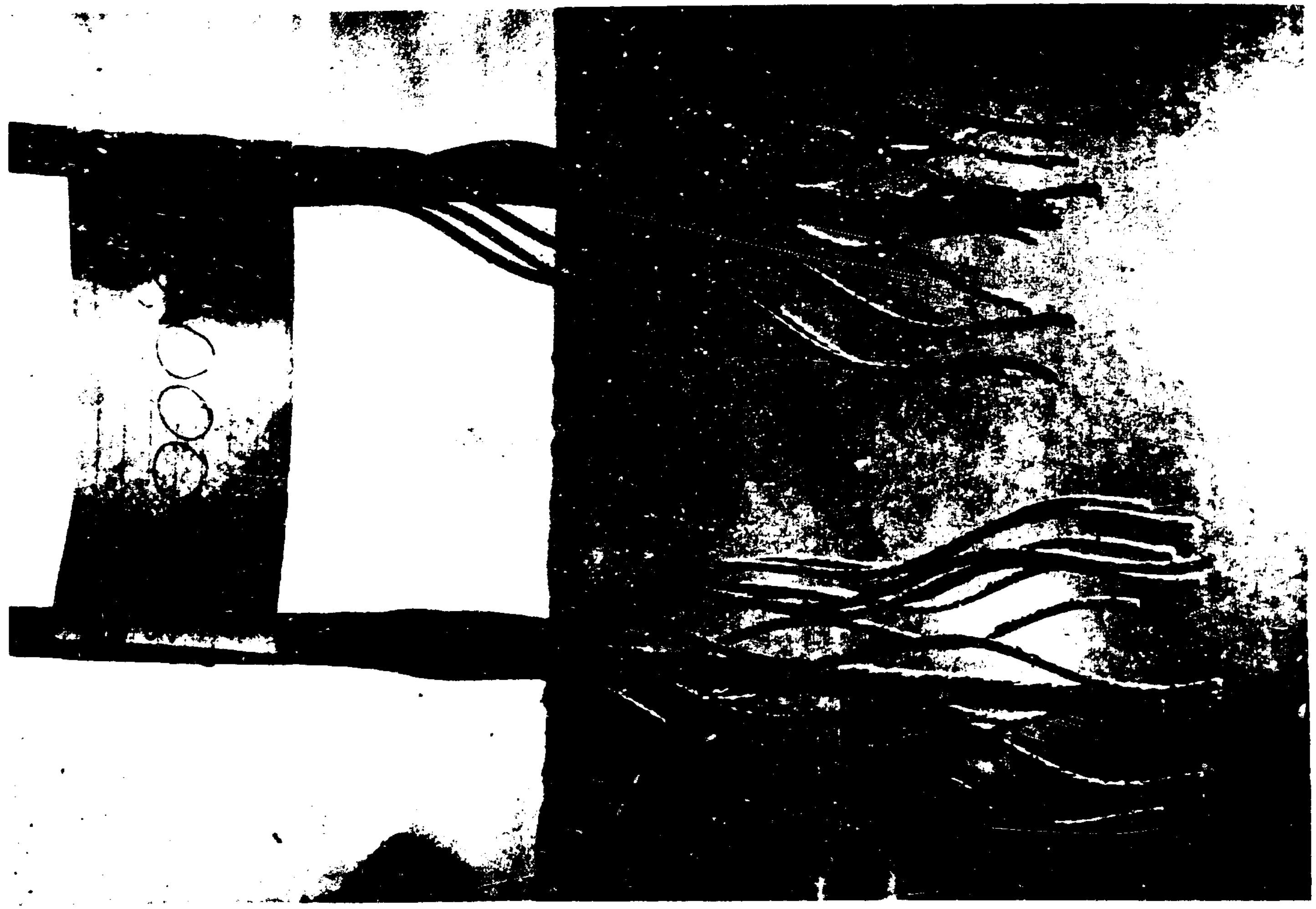

Figure 48 - Laboratory Test Results -- Cable under 10,000-Pound Tension

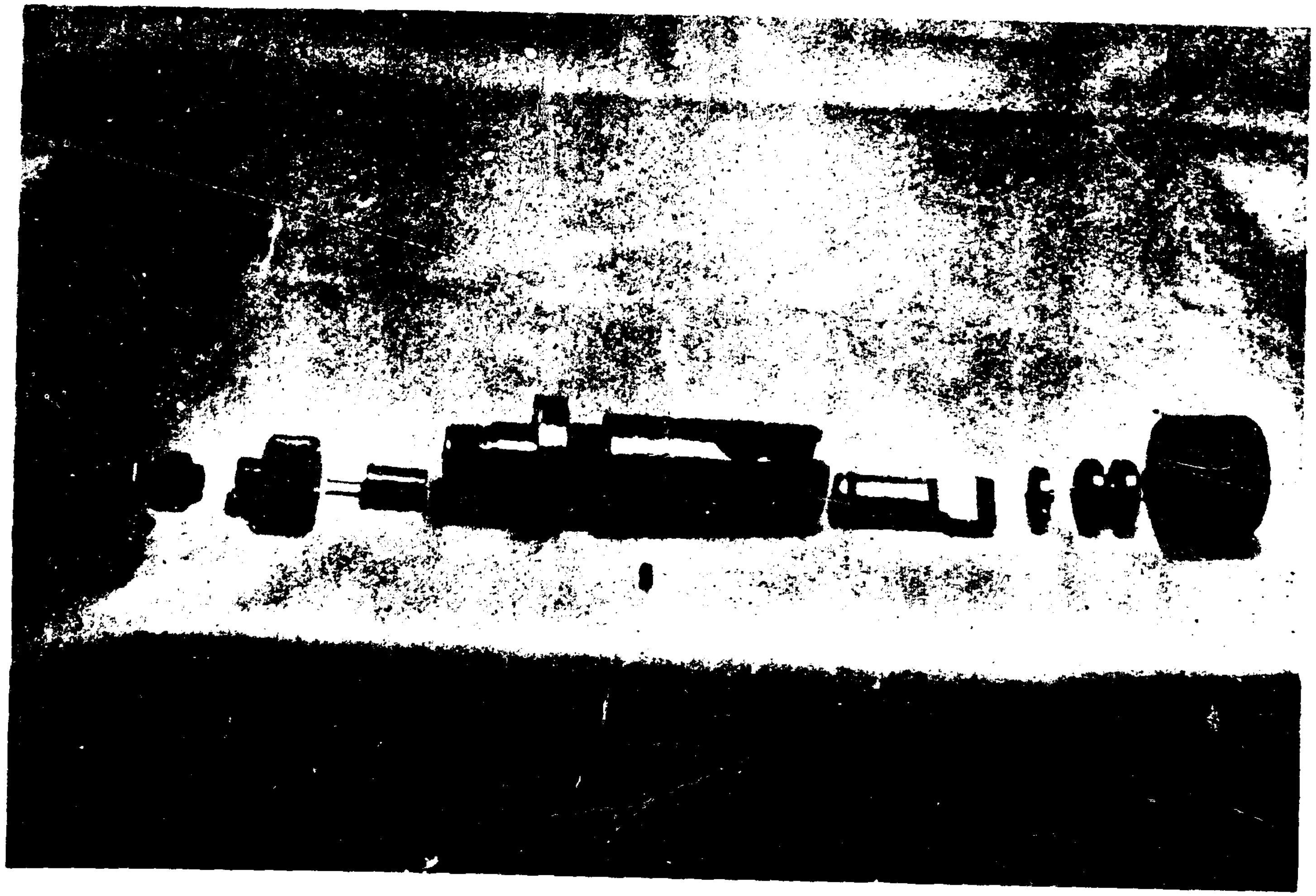

Figure 49 - Disassembled Cable Cutter

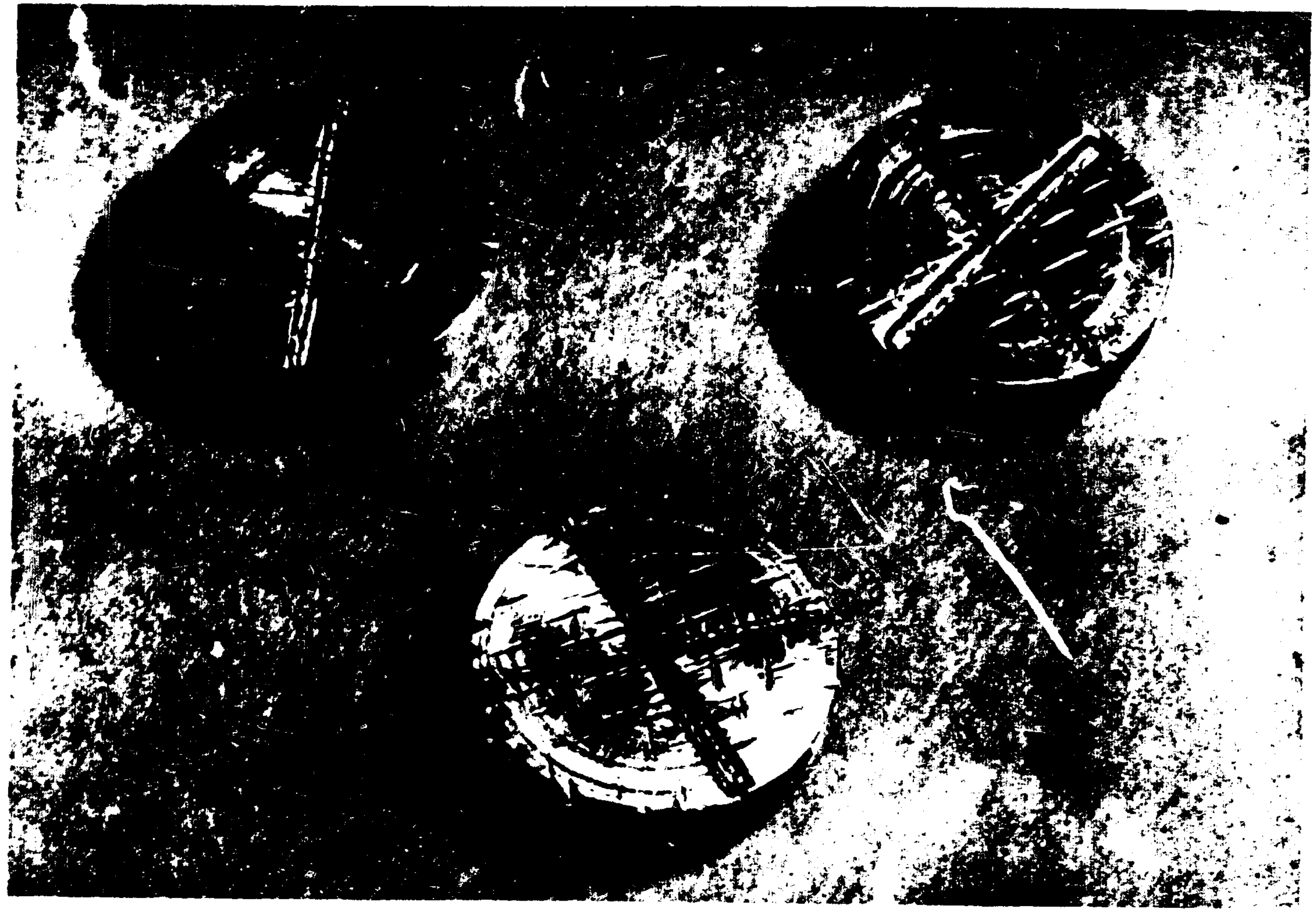

Figure 50 - Cable Cutter Anvil after Laboratory Test

resulted in no apparent deterioration of anvil effectiveness.

From the cable cutter tests described above, it was concluded that the Mine Safety Appliances cutter would safely cut the cable under all conditions expected during the flight test program.

Flight Test

The Trolley flight test program was conducted at the El Centro Naval Air Facility, California during the period from 18 April 1966 through 4 May 1966. All objectives of the program were achieved within the time programmed at the beginning of the study contract. The programmed test points were flown essentially as defined in Lockheed-Georgia's Engineering Flight Test Program, Low Altitude Airdrop Concept, ER 8291, as revised 31 March 1966.

Test Preparation - The test equipment was installed on a C-130E aircraft as shown in Figure 51. The installation shown in that figure is not to be confused with the conceptual design of an operational Trolley System. Since the purpose of the flight test was to determine parachute stability characteristics and position, the equipment used was designed to perform that task only. Operational Trolley equipment would be more compact, occupy less cargo compartment space and would not interfere with the roller system on the cargo floor.

Figure 52 shows the winch used in the test program as it was mounted on its platform and installed in the test aircraft. The hydraulic drive motor, speed reducer and chain drive system (with safety guards) can be seen on the left. The winch controls and hydraulic system heat exchangers are mounted on the right. The device used for measuring cable tension can be seen lying on the cable guard in the center of the picture.

In Figures 53 and 54 the aft platform which held the cable guide rollers, safety guillotines and cameras are shown. The 60-foot nylon extraction line which connected the parachute to the cable is shown tied to a piece of plywood mounted on the top of the cable guide framework. After deployment of the parachute the plywood was removed and stowed elsewhere in the aircraft. The large rectangular structure in the center of Figure 53 and on the left in Figure 54 is the plywood cable guard which guarded the cable between the forward and aft platforms.

The rear of the aircraft with the test equipment installed is seen in Figure [illegible]. In this photograph the two cameras used to photograph the parachute at each test point can be seen mounted on both outside edges of the aft platform. The guide rollers which restrained vertical and horizontal movement of the cable are also shown.

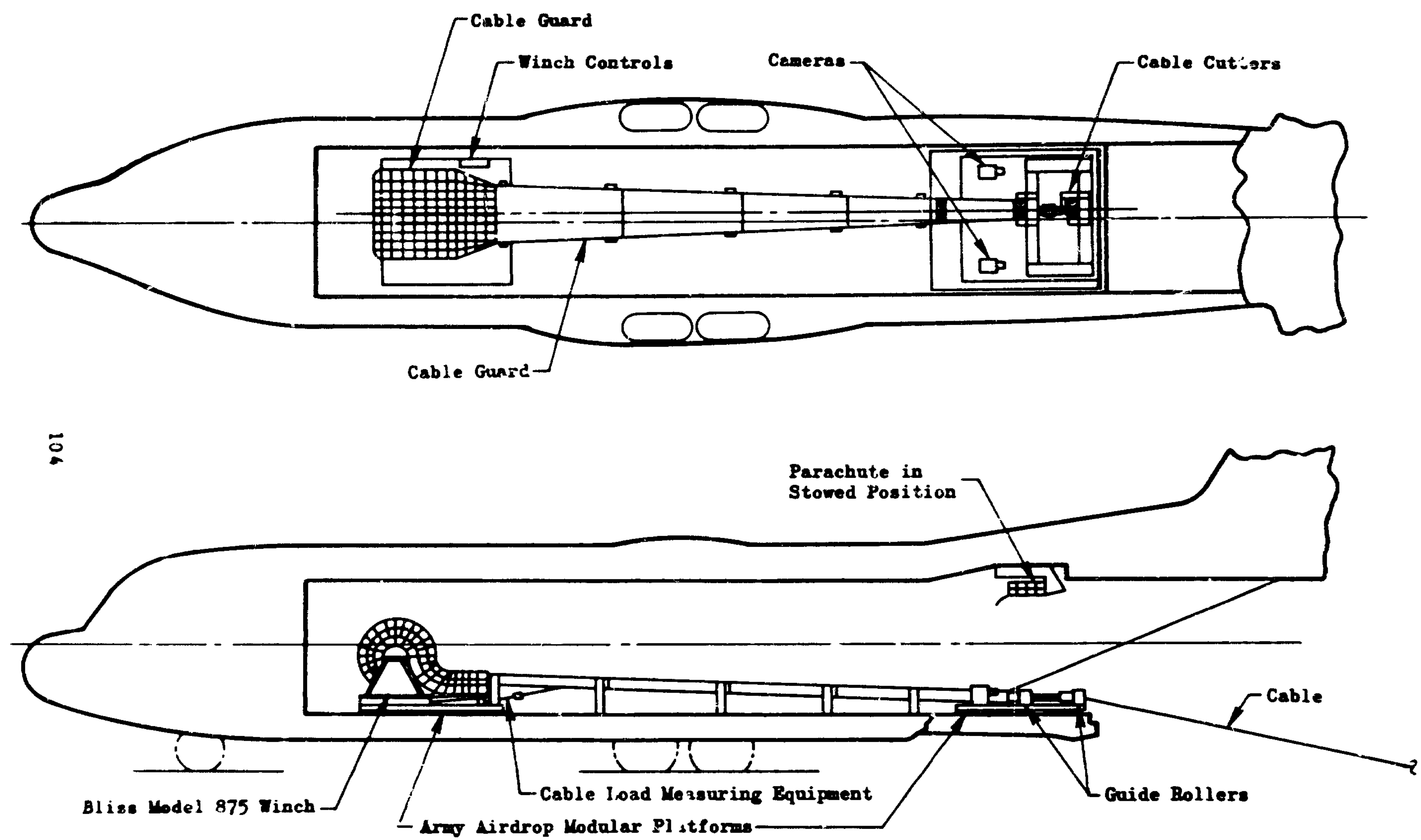

Figure 51 - Flight Test Equipment Installation on the C-130

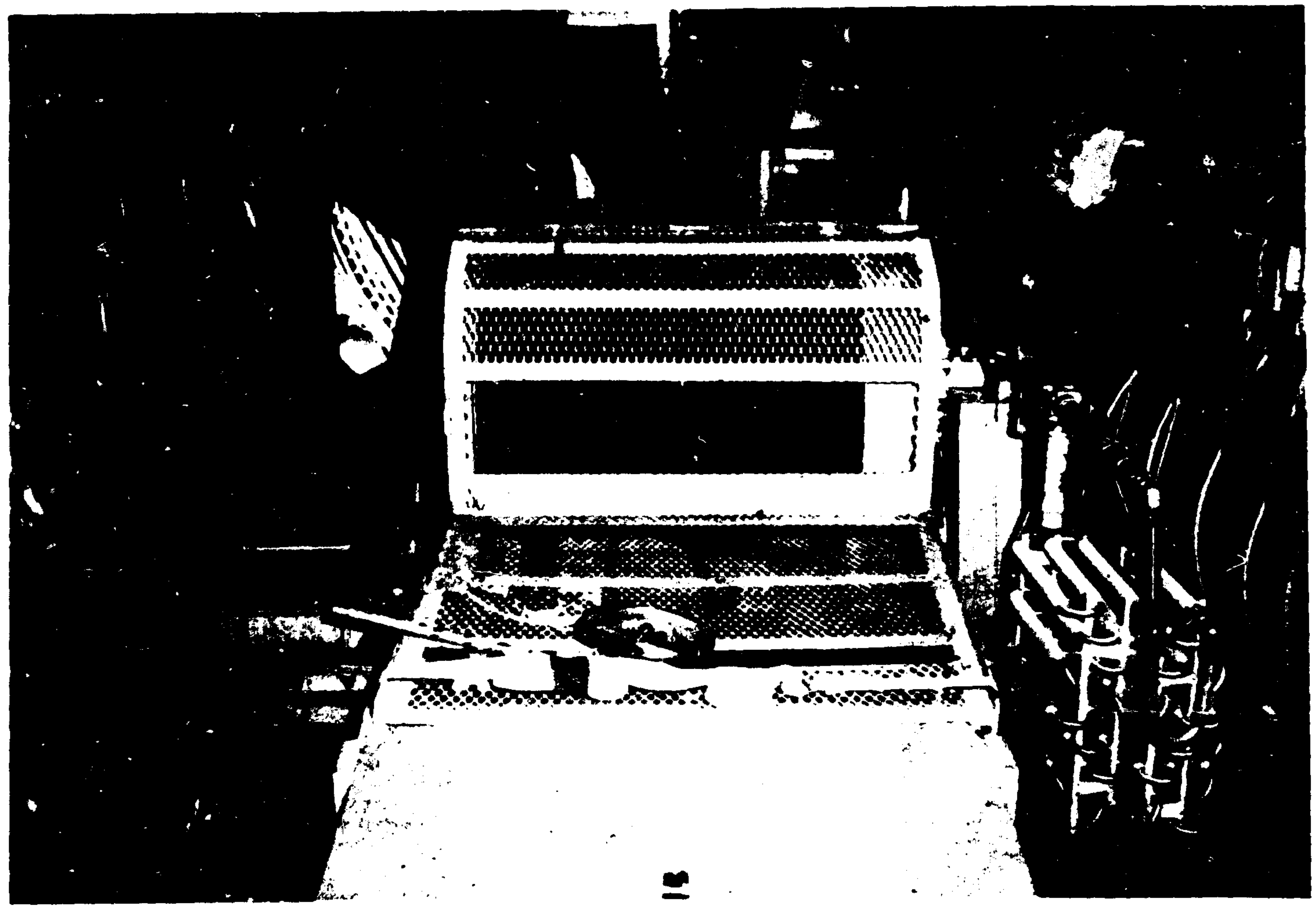

Figure 52 - Forward Platform

Figure 53 - Aft Platform -- Top View

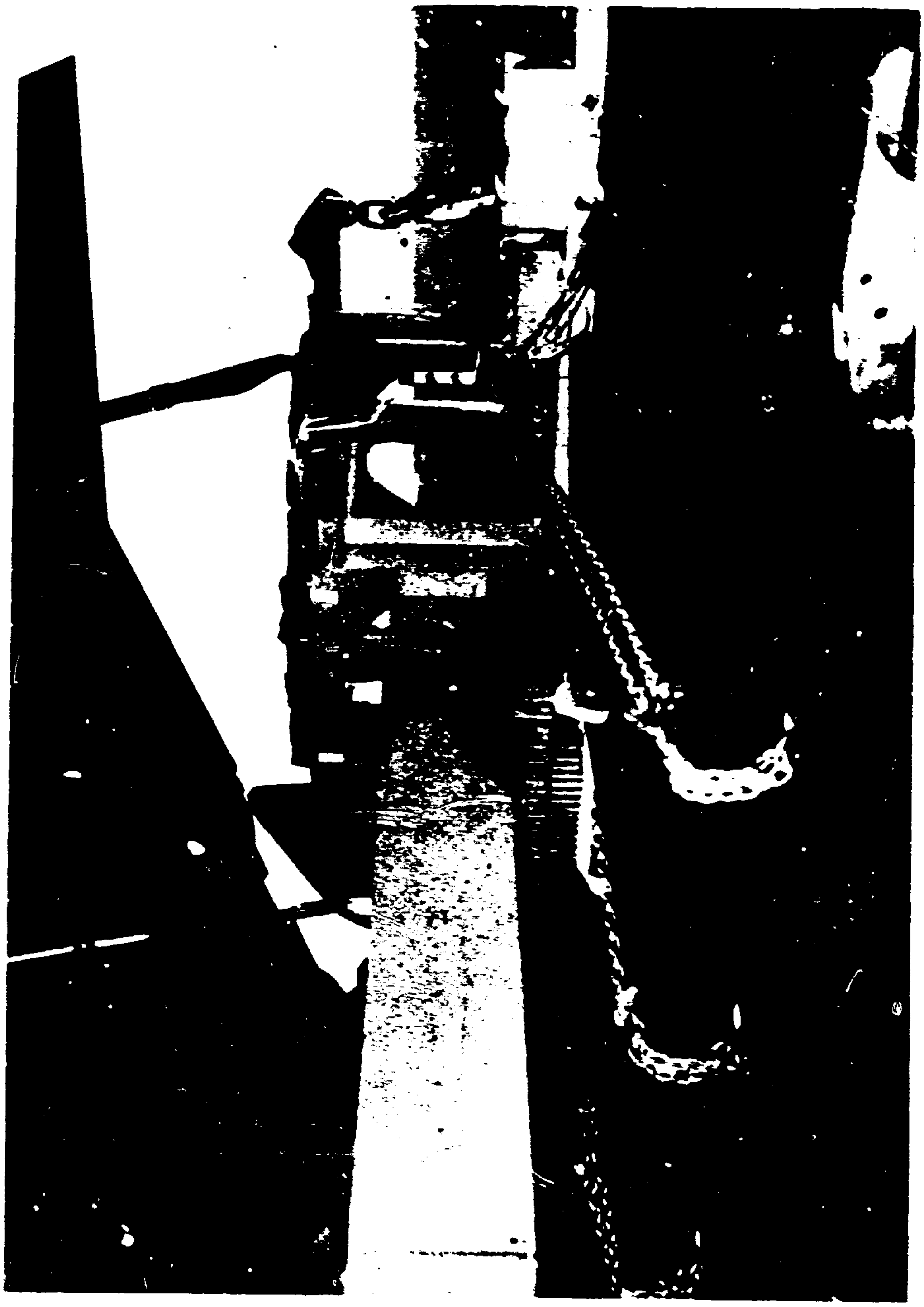

Figure 54 - Aft Platform -- Side View

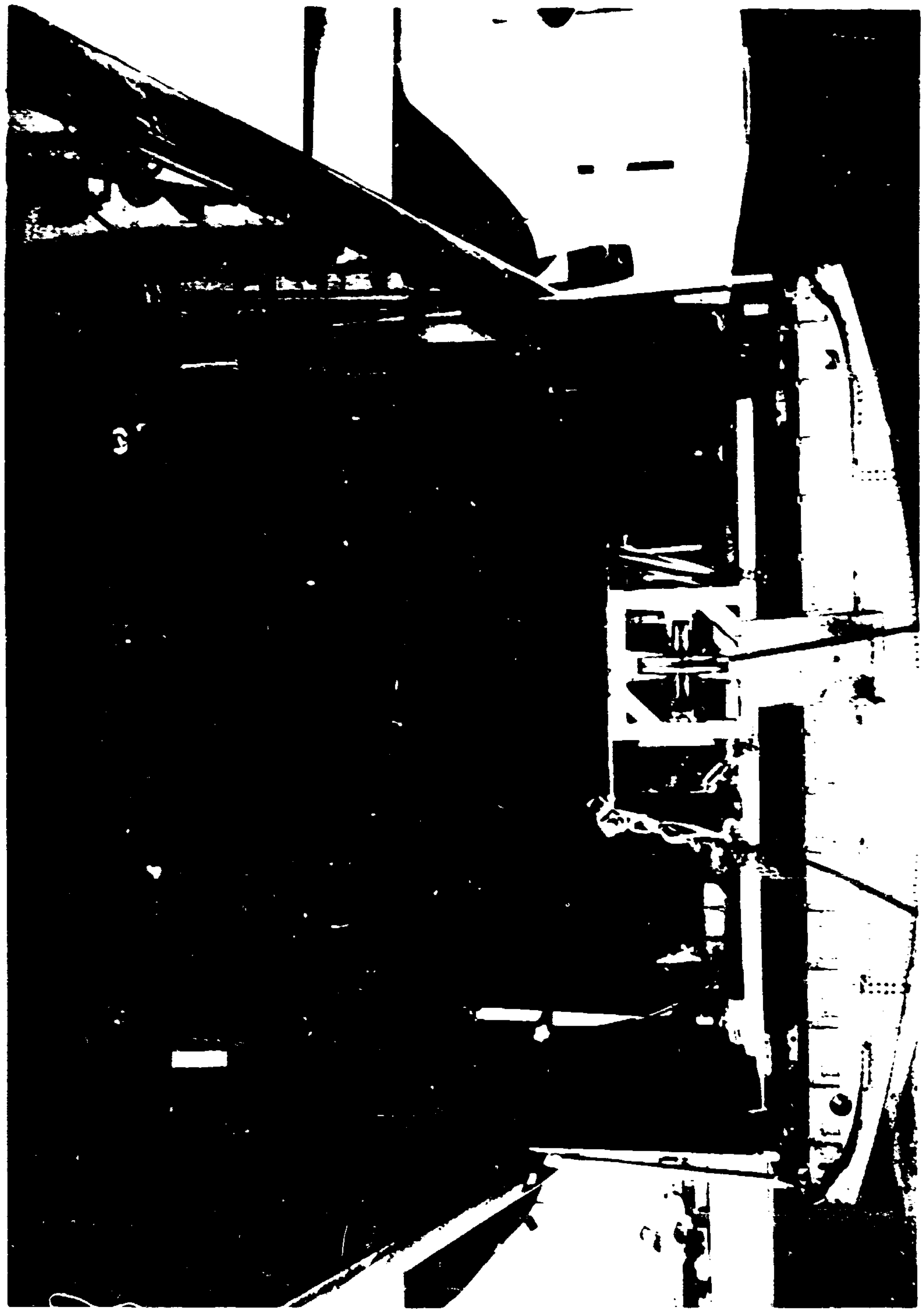

Figure 55 - Guide Rollers

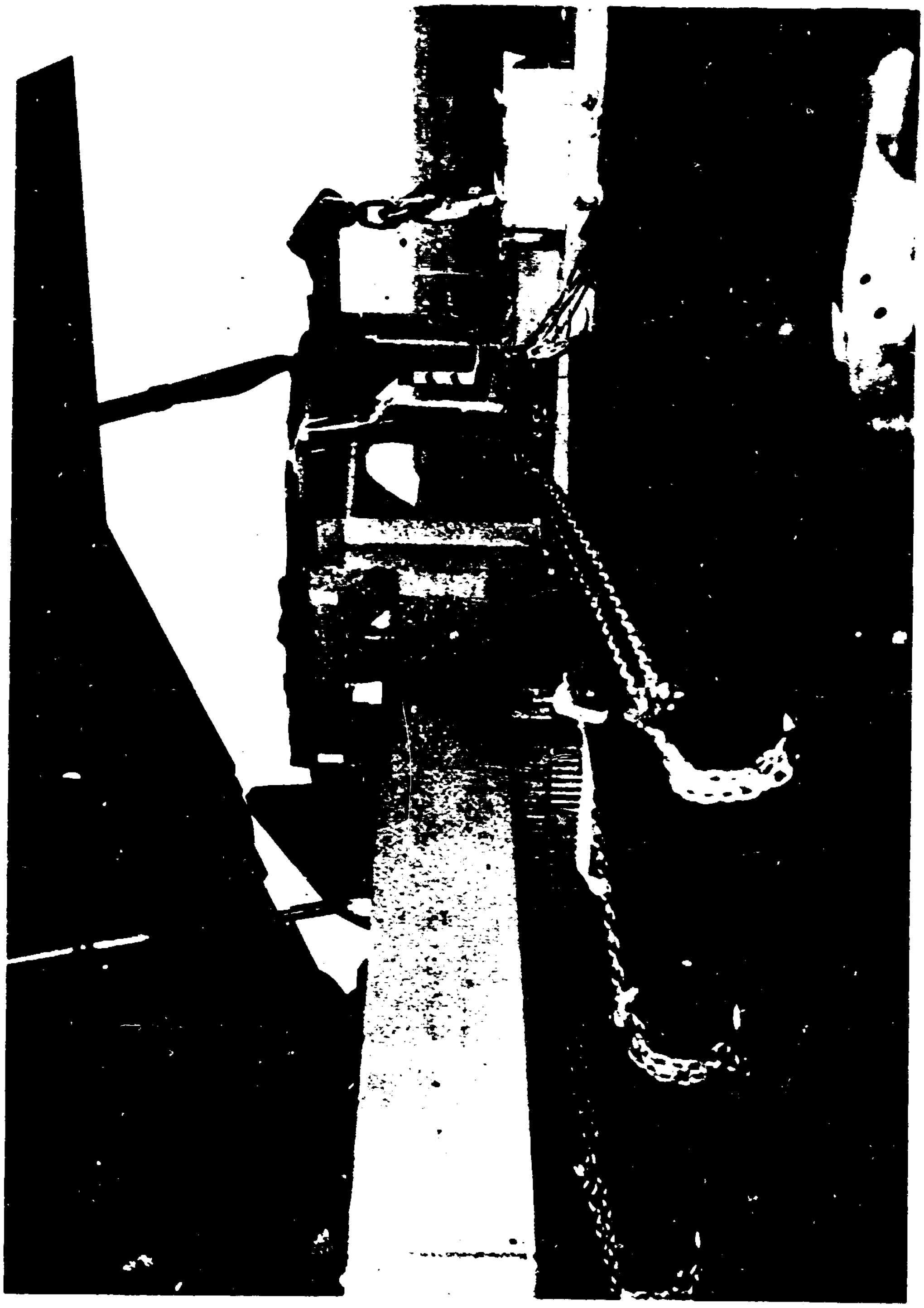

Figure 54 - Aft Platform -- Side View

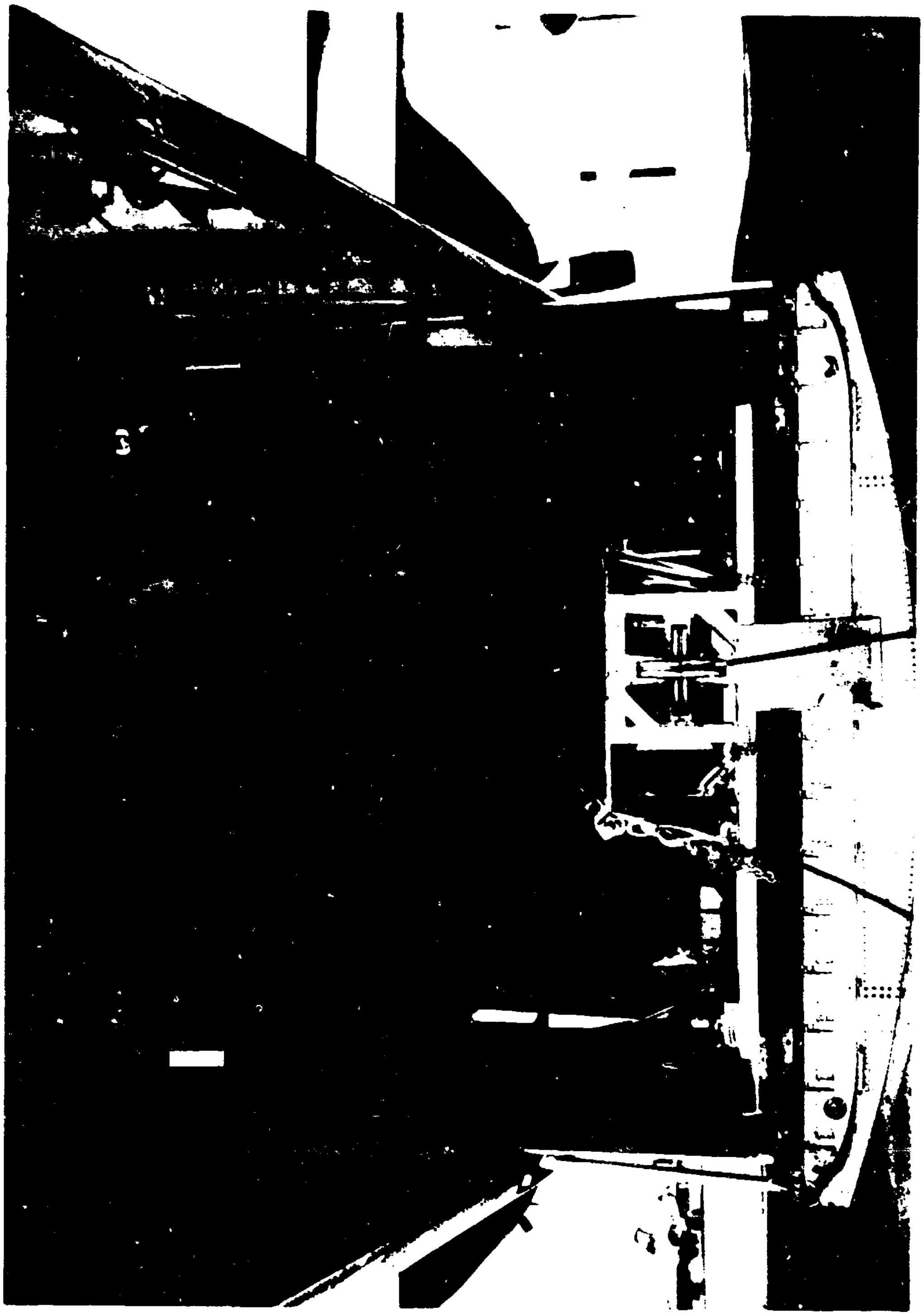

Figure 55 -- Guide Rollers

Test Results - Four flights were conducted to obtain the necessary data. Due to an El Centro requirement to support other test programs, no additional flights were possible. However, sufficient data were obtained to show the feasibility of the Trolley concept. Additional flights would have served only to reduce the scatter of data obtained. A description of each of the flights follows.

- Flight Number 1 - This flight was flown for an airspeed system check calibration against a calibrated T-33. Since the Lockheed-Georgia equipment was onboard and connected to the aircraft's hydraulic system, Lockheed test personnel participated. However, no engineering test data that were pertinent to this test program were recorded.

- Flight Number 2 - This flight was flown for data points A-1 through C-3 as defined in ER-8291. Parachute deployment at 130 KIAS and 5000 feet was normal; however, immediately after deployment, when the parachute was still within 65 feet of the C-130, rapid counter-clockwise rotation of the parachute, as viewed from the airplane, began. During this period of parachute rotation, the cable tension was measured and recorded. This operation required approximately 5 minutes after which it was noted that the cable immediately aft of the roller guide system was separated in such manner that all of the cable tension was transmitted through the center, or core strands, of the cable.

  It was decided that immediate cable and parachute separation should be accomplished to reduce the possibility of a cable break due to the overloading of the center strands. Cable and parachute separation were accomplished without difficulty by use of the "normal" cable cutter. The parachute and short cable were picked up and returned to El Centro for inspection. This visual inspection revealed no parachute abnormalities which might have been responsible for the rapid rotation.

  The cable separation occurred over approximately a length of 2 feet, and "fanned-out" to a diameter of approximately 6 to 8 inches. As previously stated, no parachute abnormalities were discovered in the post-flight inspection and the reason for parachute rotation close to the aircraft remains unexplained. Only one datum point was generated on this flight. It is shown on Table VII.

- Flight Number 3 - This flight was flown for data points A-1 through F-3 as defined in ER-8291 except that the 125 KIAS points shown at the 1500-foot cable length should be 130 KIAS. Parachute deployment at 130 KIAS was normal. No significant parachute rotation resulted.

Run No.	1	
Cable Length - Feet	64	
Airspeed KCAS	130	
Cable Tension - Pounds	6780	Flight aborted due to parachute rotation and cable separation.
Fuel Weight - Pounds		
Parachute h - Feet		
Airplane Weight - Pounds		

Test Date 28 April 1966

Table VII- Flight No. 2 Test Data

To avoid possible problems associated with parachute rotation, it was immediately deployed to the 1000-foot point. At no time during this deployment did significant parachute rotation occur. Generally, the parachute and cable were very stable, and the test data points were obtained more rapidly than anticipated. The entire schedule of the test data points, as defined on page 5 of ER-8291, was obtained during this flight. It was recognized during flight that considerable data scatter existed; however, there was insufficient fuel in the aircraft for the test of questionable points to be repeated. Data from this flight are shown on Table VIII.

Figure 59 is a photograph taken during this flight and is typical of all test conditions. The drag parachute is being towed on 1000 feet of cable by the C-130 at a flight speed of 150 knots. The shape of the cable can be seen and it appears that the parachute, at the extreme right, is at the lowest point of the parachute/cable combination.

Run No.	A-1	B-1	C-1	D-1	E-1	F-1	G-1	H-1	I-1
Cable Length	1,000	1,000	1,000	1,500	1,500	1,500	2,000	2,000	2,000
Airspeed*	130	150	110	110	130	150	110	130	150
Cable Tension**	5,875	8,180	4,175	4,475	5,925	8,025	4,425	5,825	7.675
Fuel Weight	28,000	25,700	24,400	21,400	19,500	18,300	10,400	11 500	12,300
Parachute h	-85	-105	-110	-200	-100	-75	-280	-220	-160
Airplane Weight	117,754	115,454	113,754	111,154	109,254	108,054	100,154	101,254	102,054

Test Date 29 April 1966

Zero Fuel Weight 89,754 Lb.

*Corrected to the values shown by the next step**

**(Measured cable tension - 125 Lb) $\left(\frac{V_{corrected}}{V_{test}}\right)^2$

Table VIII- Flight No. 3 Test Data

Figure 56 – Typical Test Point -- 150 Knots

o Flight Number 4 - This flight was flown primarily to define the "q-hump" behind the airplane that was believed to exist at about 100 to 300 feet aft of the empennage. Cable tensions were also obtained for cable lengths in 100-foot intervals out to 2000 feet at 110 KIAS.

Still-photographs of tow cable geometry were obtained at each 500-foot interval and at 1300 feet. A set of three data points (at 110, 130, and 150 KIAS) with 1300 feet of cable deployed was obtained since the 1300-foot cable length appeared, from computer results, to be a realistic length. Also, 30-degree banked turns in both directions were performed to determine parachute-tow cable stability at 130 KCAS and to note any adverse affects on airplane handling characteristics. Parachute and tow cable stability were considered excellent at 1300 feet and 130 KCAS and in turns with up to 30 degrees of bank. However, with 1000 feet of the cable deployed the parachute apparently "rides" in the airplane wake and produces vertical and lateral oscillations of the parachute which, in turn, feed the tow cable into a "jump-rope" type of oscillation. Data from this flight are shown in Table IX.

All useful data from the test program are tabulated in Table VII, VIII and IX . Plots of the speed-corrected and force-corrected data are shown in Figures 57 and 58. From Figure 57 it is seen that neither "q" variation aft of the airplane nor a force increase due to the gravity component of the cable is evident. These variations, if they exist in terms of cable tension at the aircraft, are of such magnitude that they are lost in the scatter of data. Figure 58 data present such scatter that little use can be made of this information. This scatter is adequate evidence that a more accurate means of measuring differential height between airplane and parachute must be developed. The several photographic attempts to determine the difference in height between the airplane and parachute resulted in no useable information being obtained. The results included in this report were obtained by comparing the chase airplane altimeter with the tow airplane altimeter.

These data also suggest that the vertical flight path of the towing aircraft may have been somewhat oscillatory and may have induced a vertical oscillation of unknown phase relationship into the tow cable and parachute system. Since vertical distance above the surface onto which a package may be delivered by this concept is critical, further investigation of the airplane-parachute dynamics may be warranted.

From the results of the test program, certain conclusions can be drawn:

Run No.	1	2	3	4	5	6	7	8	9
Cable Length	64	200	300	400	500	600	700	800	900
Airspeed*	110	110	110	110	110	110	110	110	110
Cable Tension**	4,575	4,375	4,475	4,375	4,275	3,975	4,175	4,275	4,170
Fuel Weight	38,150	37,750	NA	NA	37,150	36,550	NA	NA	NA
Parachute h	0	-90	0	-80	-120	-110	-100	-90	-130
Airplane Weight	128,304	127,904	NA	NA	127,304	126,704	NA	NA	NA

Test Date 3 May 1966

Zero Fuel Weight 90,154 Lb.

*Corrected to the values shown by the next step**

**(Measured cable tension - 125 Lb) $\left(\frac{V_{corrected}}{V_{test}}\right)$

Table IX - Flight No. 4 Test Data

Run No.	10	11	12	13	14	15	16	17	[illegible]
Cable Length	1,000	1,100	1,200	1,300	1,300	1,300	1,400	1,500	1,600
Airspeed*	110	110	NA	110	130	150	110	110	110
Cable Tension**	4,175	4,325	NA	4,150	5,725	7,525	4,425	4,225	4,220
Fuel Weight	38,850	35,600	35,450	35,250	34,850	34,650	34,050	33,550	33,350
Parachute h	-100	-160	-150	-170	-130	-90	-120	-240	-240
Airplane Weight	126,034	125,754	125,604	125,404	125,004	124,804	124,204	123,704	123,504
						For photo coverage only	For photo coverage only	For photo coverage only	For photo coverage only

Test Day 3 May 1966

Zero Fuel Weight 90,154 Lb.

*Corrected to the values shown by the next step**

**(Measured cable tension - 125 Lb)$\left(\frac{V_{corrected}}{V_{test}}\right)$

Table IX- Flight No. 4 Test Data, continued

Run No.	19	20	21	22	23	24	25	26
Cable Length	1,700	1,800	1,900	2,000	1,500	1,300	1,000	500
Airspeed*	110	110	110	110	110	110	110	110
Cable Tension**	4,575	4,225	4,575	4,475	NA	NA	NA	NA
Fuel Weight	33,750	32,750	32,550	31,850	30,500	29,550	28,550	27,450
Parachute h	-250	-270	-230	-190				
Airplane Weight	123,904	122,904	122,704	122,004	120,654	119,704	118,704	117,604

Test Day 3 May 1966

Zero Fuel Weight 90,154 Lb.

*Corrected to the values shown by the next step**

**(Measured cable tension - 125 Lb.) $\left(\frac{V_{corrected}}{V_{test}}\right)$

Table IX - Flight No. 4 Test Data, continued

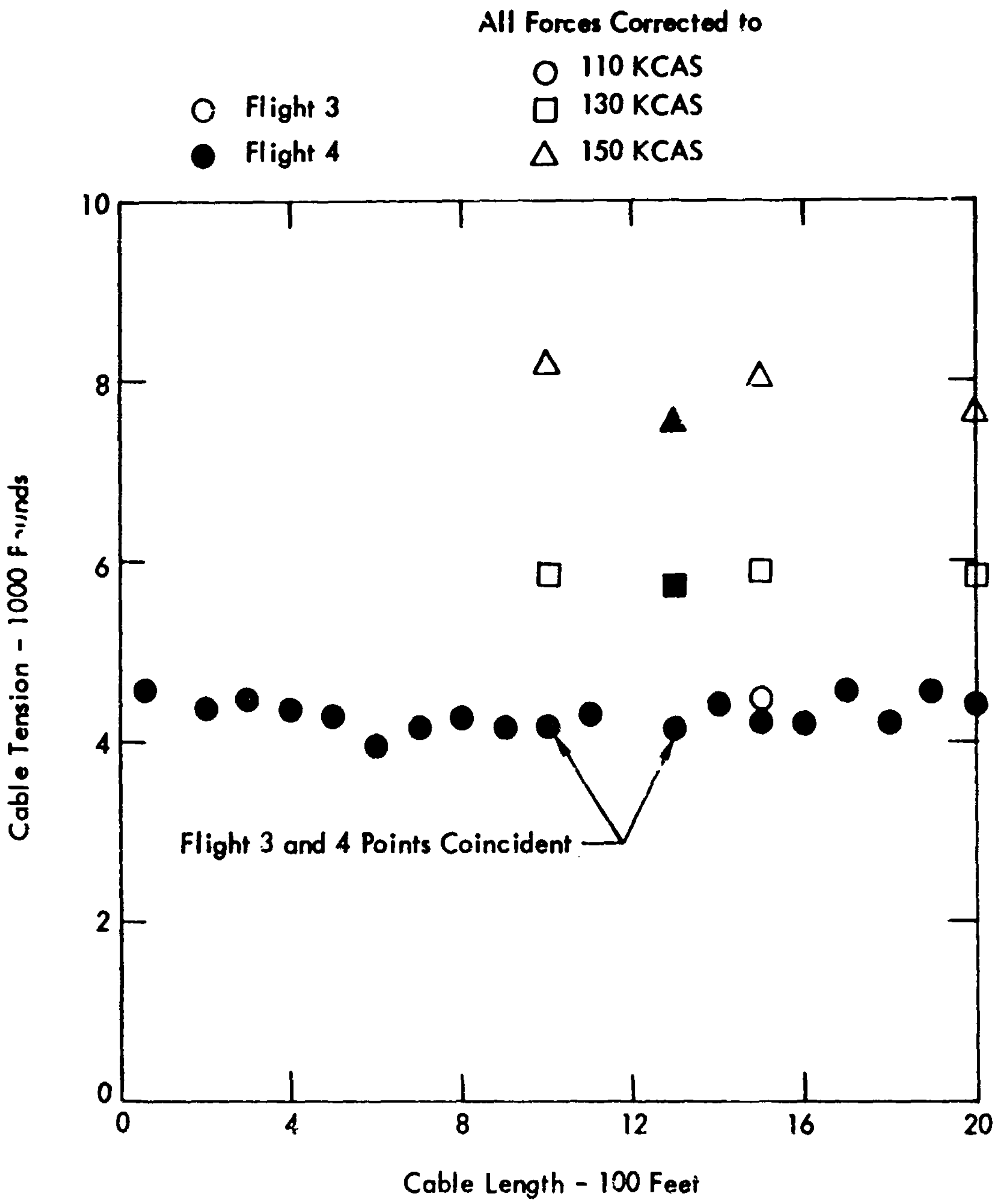

Figure 57 - Cable Tension vs. Cable Length

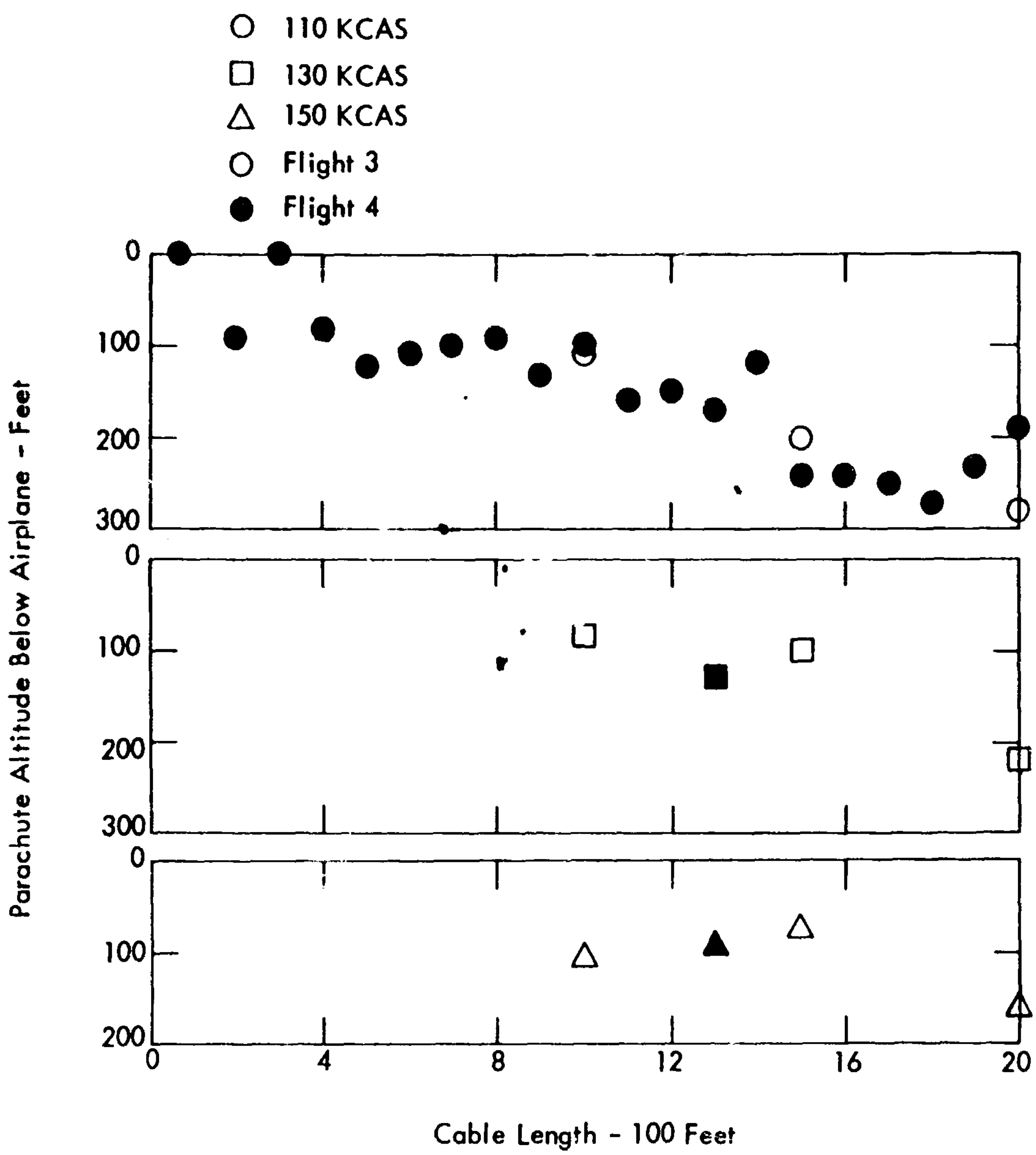

Figure 58 - Parachute Altitude at Various Cable Lengths

1. Deployment, towing, and separation of high-drag parachutes with 5/8-inch steel cable used in these tests should not present any major problems in Trolley operation.

2. Cable rebound at severence presented no energy dissipation problem. Cable rebound within the tunnel was as anticipated.

3. No adverse affects of the towed parachute on airplane handling characteristics were noted by the Air Force flight crew.

4. Stability of the parachute and tow cable was excellent in all phases of flight except for the 1000-foot length cable in the turns as previously stated.

5. Some method of preventing parachute rotation may be required to relieve undesirable effects on the tow cable.

6. Little or no parachute damage will occur while it is being towed for a Trolley drop.

7. Test results show nothing which would preclude further development of the Trolley concept.

III. Conclusions and Recommendations

As a result of this investigation the Trolley system conceptual design has progressed to a point where hardware development is entirely feasible. Significant conclusions of this study are summarized below:

- o Unit drop weights of 2000 to 10,000 pounds can be airdropped from a C-130.
- o Accuracy of airdrop is much better than that available with present airdrop systems and results in much smaller drop zone requirements.
- o Vertical impact velocity is sufficiently low so that energy absorbers can be eliminated.
- o When aircraft velocity is 120 knots, horizontal impact velocities are compatible with those in conventional airdrops.
- o Cost-per-delivered pound of airdrop items is significantly reduced.
- o Rigging is simplified and rigging time is reduced - thereby reducing manpower requirements.
- o The wheeled trolley assembly can be replaced with a cheaper and simpler slide assembly.
- o The cable can be routed under the drop platform thereby eliminating the need for overhead routing pulleys and equipment. This greatly simplifies the installation of the equipment in the airplane and makes more of the cargo compartment available for payload.
- o The system as conceptually designed for the C-130 can be adapted to the C-141 for 10,000-pound drops or redesigned to permit delivery of up to 20,000 pounds from the C-141.
- o The system can be adapted to the CV-2 and CV-7 aircraft with reduced unit drop weight capability.

Better Trolley system performance can be attained if the following recommendations are followed during a hardware development program:

- o Design the system and "tune" it for various drop weights to one aircraft speed - preferably a relatively low speed such as 120 knots.

- Investigate Trolley concept capability above the 500-foot maximum ceiling placed on it by the Work Statement of the present study.

- Coordinate with vehicle manufacturers to determine the maximum impact load capabilities of airdropped vehicles.

In summary, the Trolley concept has been proven feasible by analysis and limited component testing and is ready for hardware development to prove its operational worth. No breakthrough in technolcgy is required for further development.

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USAF. Cargo Loading, T.O. 1C-141A-9, 27 October 1965

USAF. C-130 Aircrew Operational Procedures, AFM 55-130. 30 October 1964

USAF. Criteria for Non-Standard Airdrop Loads. Aeronautical Systems Division, AFSC, Wright-Patterson AFB, Ohio (Undated)

USAF. Radar Set AN/APN-22, MIL-A-38156 (USAF) 19 March 1964

GLOSSARY

Symbol		Units
D	Drag	Pounds
F	Force	Pounds
g	Gravity	Ft/Sec^2
I	Moment of Inertia	Slug - ft^2
K	Parachute Drag	Pounds
L	Lift	Pounds
m	Mass of Airplane	Slugs
M	Pitching Moment	Foot/Pounds
T	Thrust	Pounds
U	Aircraft Velocity	Ft/Sec
W	Weight	Pounds

Greek

α	Flight Path Angle	Degrees
β	Angle between Parachute and Horizontal after Extraction	Degrees
γ	Angle of Attack	Degrees
δ	Flap Deflection	Degrees
θ	Pitch Angle	Degrees
ϕ	Pendulum Cargo Angle	Degrees
ω	Trailing Cable Angle	Degrees

Subscripts

a	Airplane
a.c.	Aerodynamic Center of Gravity
c	Cargo
c.g.	Center of Gravity
D	Cable Support in Airplane
e	Elevator

Subscripts

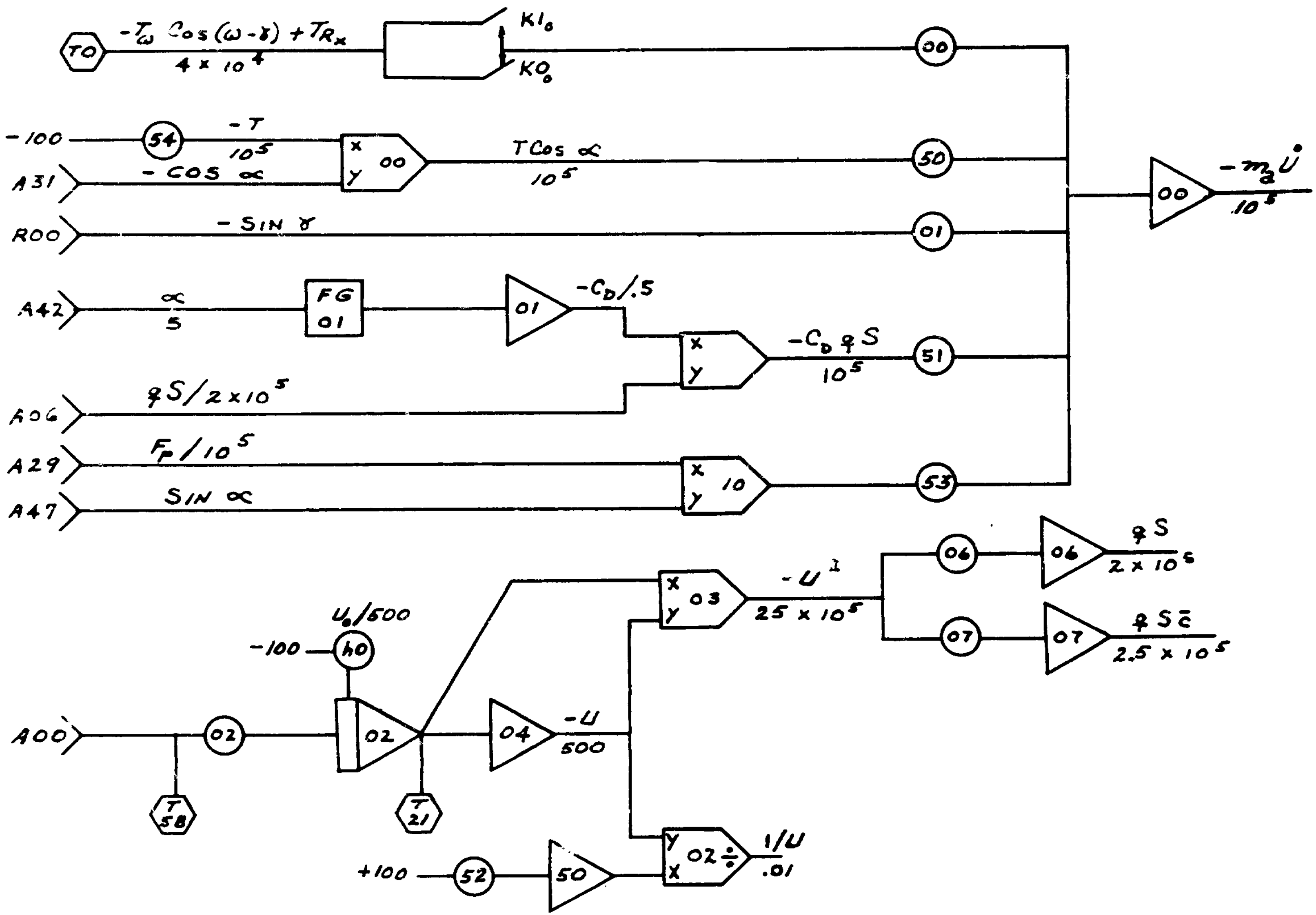
R	Resultant
P	Parachute
X	X direction
Z	Z direction

APPENDIX I

ANALOG WIRING DIAGRAMS

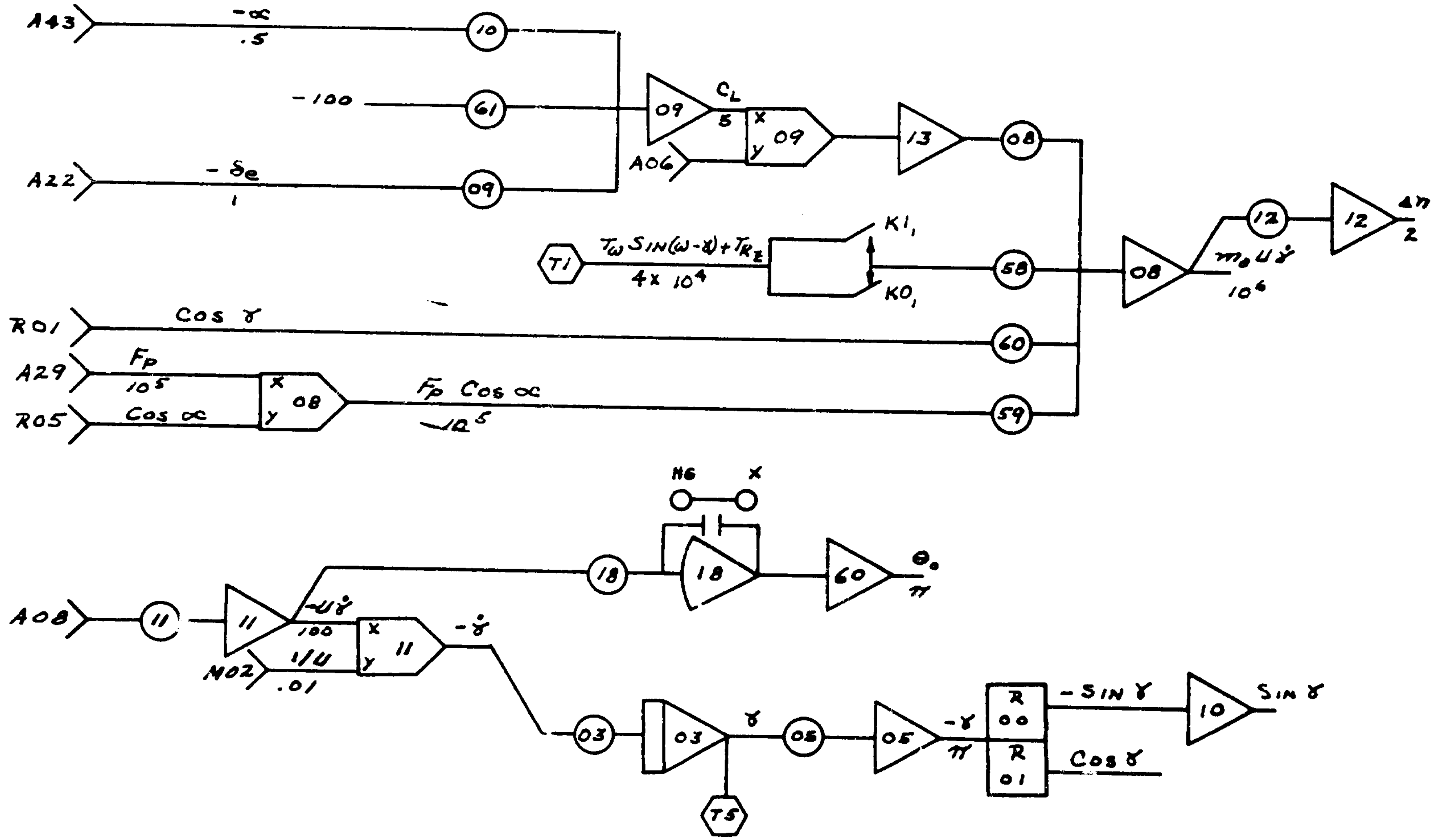
The equations of motion were programmed for solution on a Beckman-Ease analog computer. Figures 68 through 80 show the symbolic wiring diagrams along with the equations. Each wiring diagram describes the scaled equation which is used to derive the magnitudes of the various parameters.

Preparation of the data for analog computation includes the calculation of the values of lift, drag, and pitching moment coefficients for the C-130 airplane along with the servo-set coefficient potentiometer settings and input gains for each run.



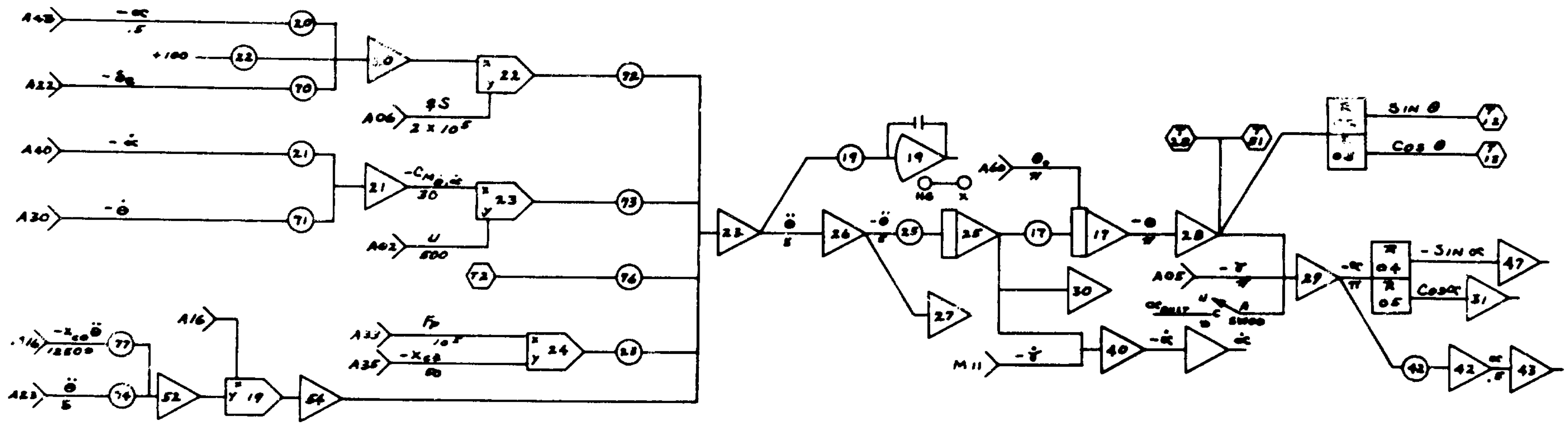
$$\Sigma F_x = m_a \dot{U} = T \cos\alpha - W_a \sin\gamma - C_D f(\alpha)\, qS + F_p \sin\alpha + (T_{R_x} - T_{D_x}) \cos\alpha$$

Figure 68 - Analog Wiring Diagram with Equation of Aerodynamic Forces Summed in the X Direction



$$\Sigma F_Z = -m_a U\dot{\gamma} = W_Z \cos\gamma - L, f(\alpha) + L, f(\delta_e) + F_p \cos\alpha + (T_{D_Z} + T_{R_Z}) \sin\alpha$$

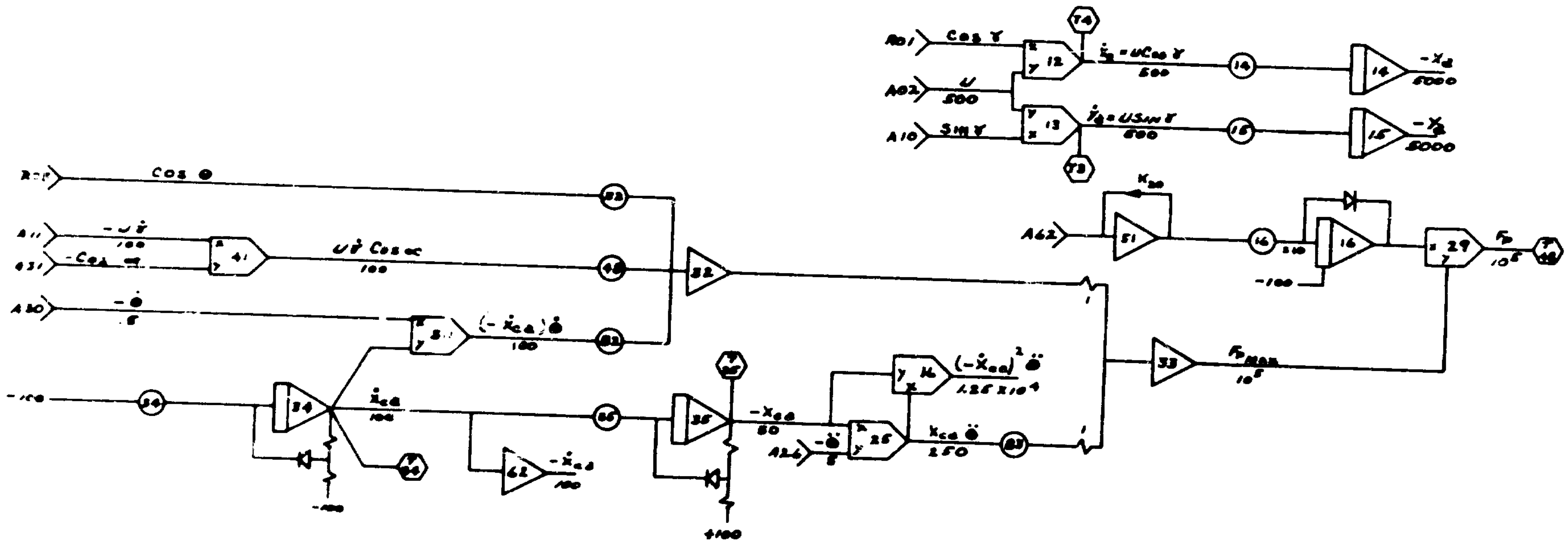
Figure - Analog Wiring Diagram with Equation of Aerodynamic Forces Summed in the Z Direction



$$\Sigma M_{cg} = I\ddot{\theta} = M_{a.c.}, f(\alpha) + M_{\dot{\theta}}\dot{\theta} + M_{\dot{\alpha}}\dot{\alpha} + M_1 f(\delta_e) + F_p X_{cg}$$

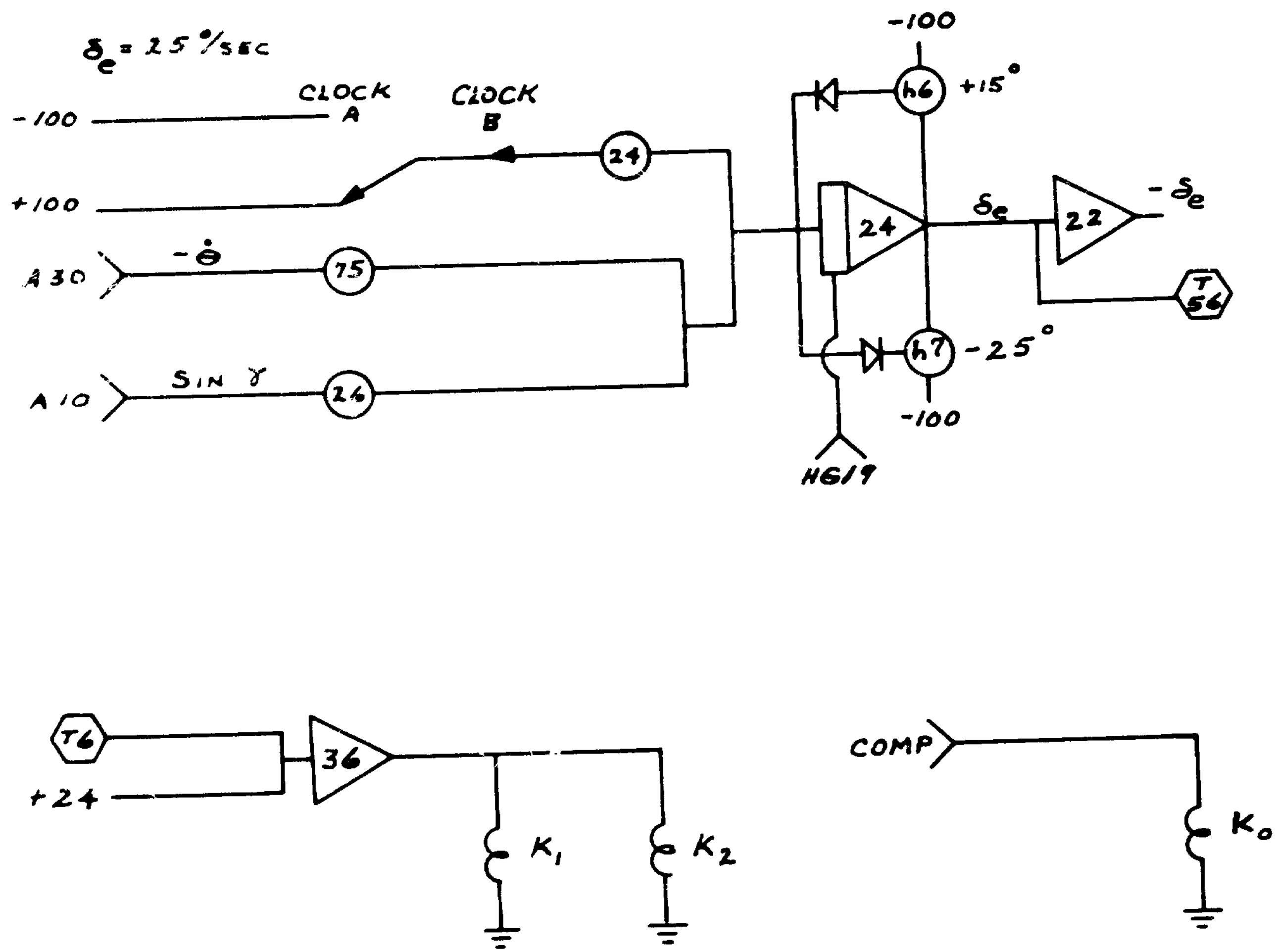
$$\gamma = \theta - \alpha \;;\quad \dot{\theta} = \int \ddot{\theta}\, dt$$

Figure 61 - Analog Wiring Diagram with Equations of Aerodynamic Moments Summed about the Airplane Center-of-Gravity



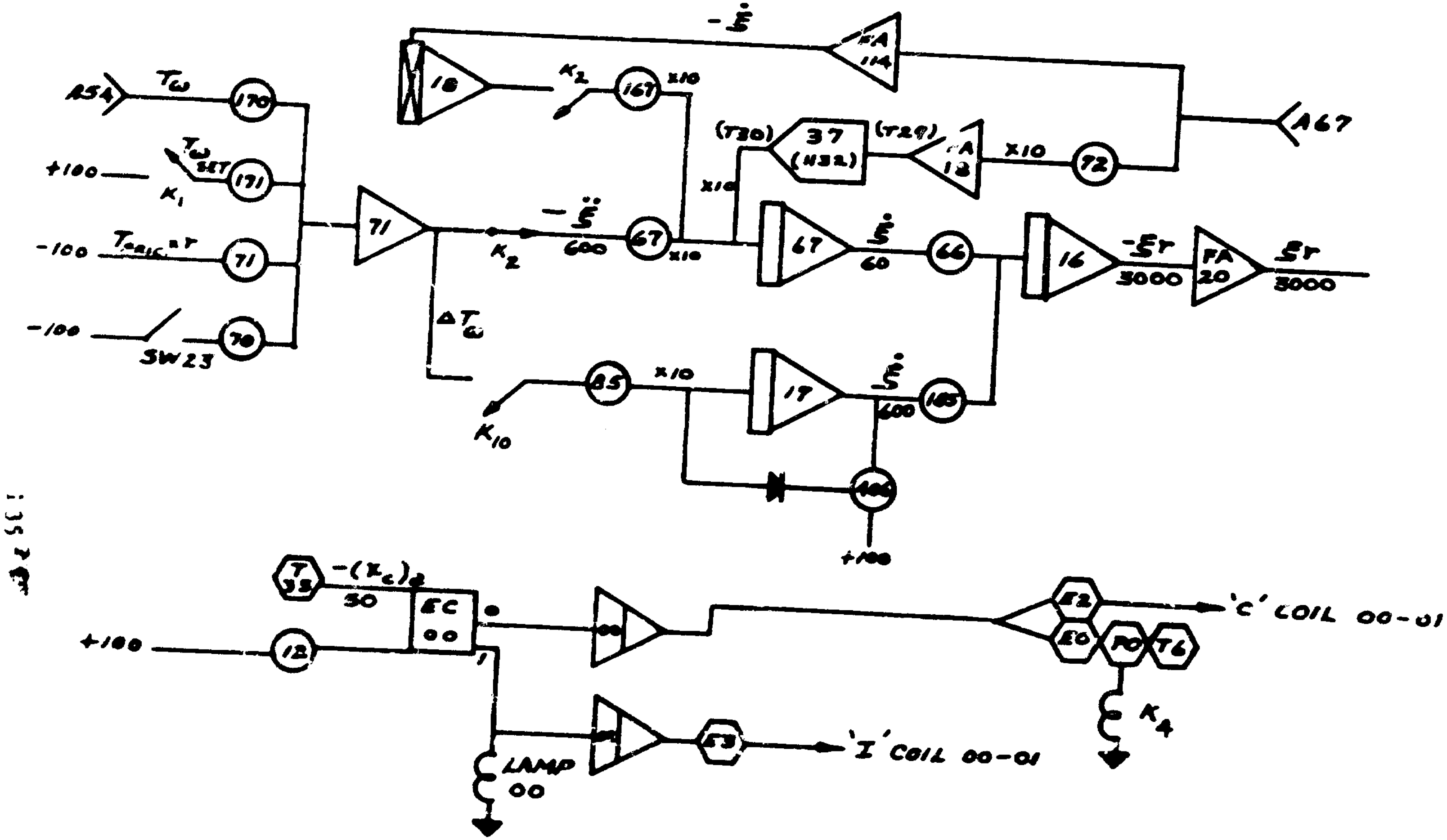
$$F = W_c \cos\theta + m_a U\dot{\gamma}\cos\alpha - m_c \dot{\theta}\dot{x}_c - m_c x_{ca}\ddot{\theta} \quad ; \quad X_a = \int \dot{X}_a\, dt \quad ; \quad Y_a = \int \dot{Y}_a\, dt$$

Figure 62 - Analog Wiring Diagram with Equations of Platform Force



$$\delta_e = K\dot{\theta} + K \sin\gamma + F_{PILOT}$$

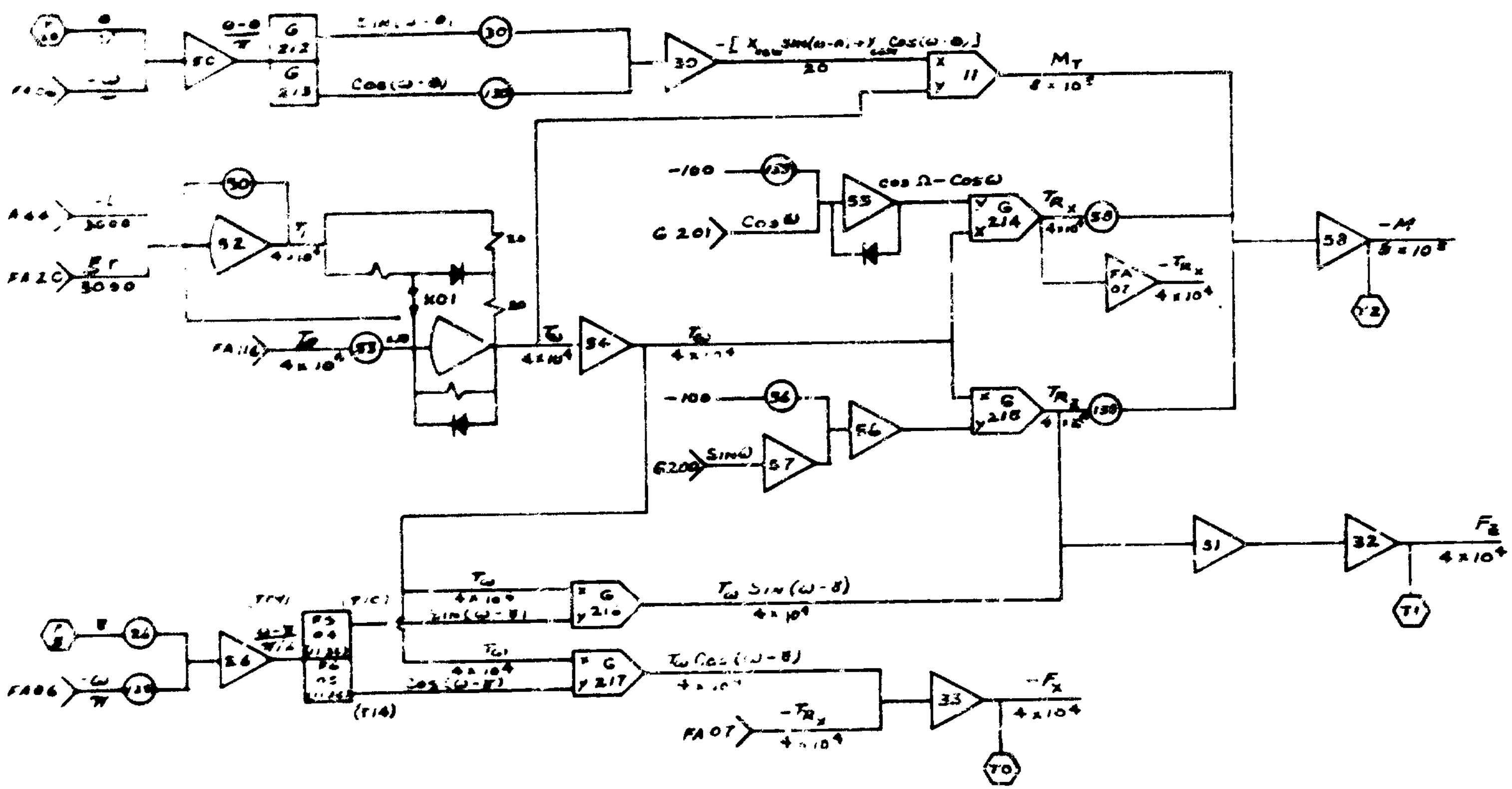
Figure 6 3 - Analog Wiring Diagram of Elevator



$$T_\omega r_1 - T_{FRIC.} r_2 - T_{\omega_{SET}} r_3 = I_w \ddot{E}$$

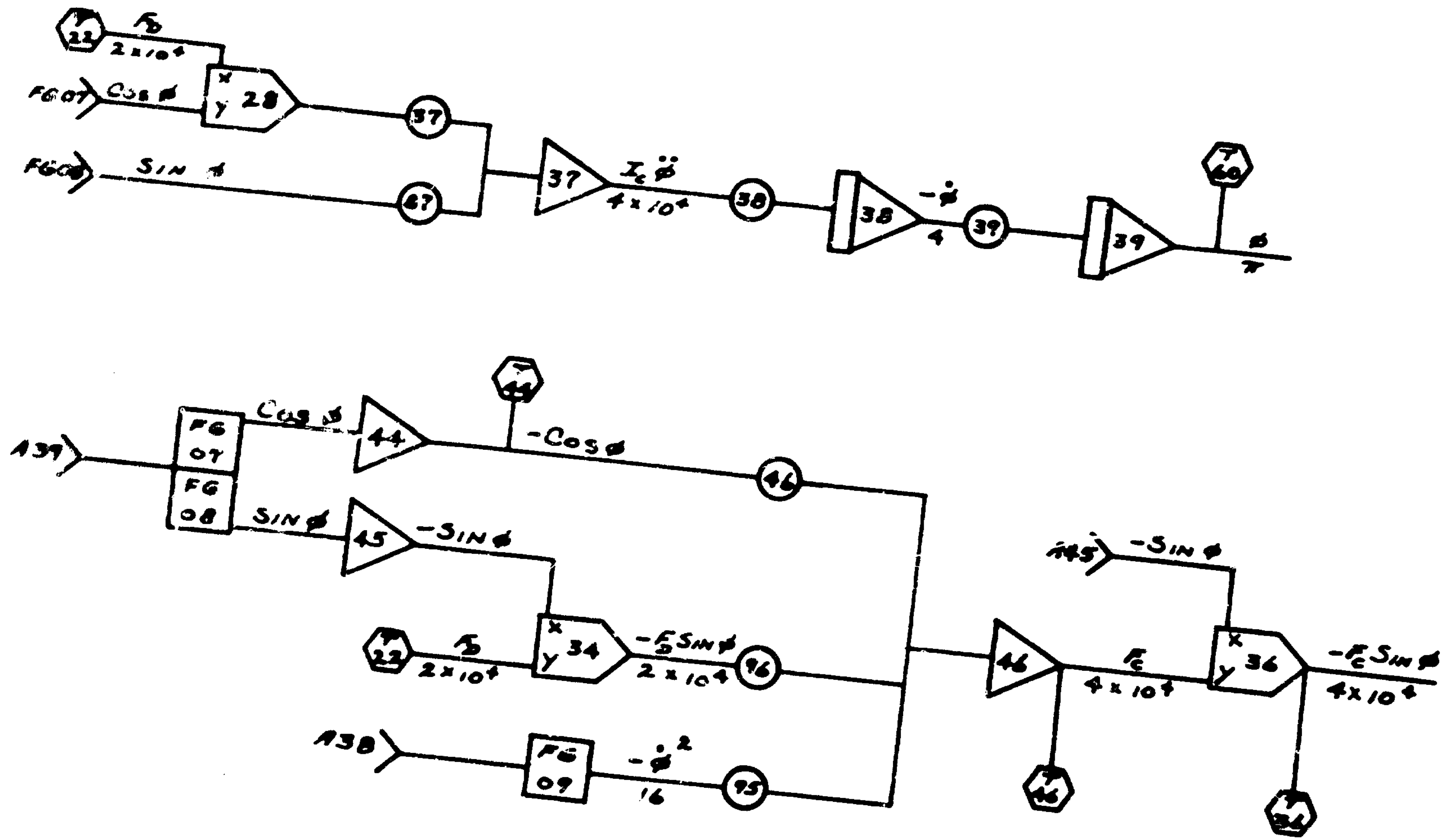
Figure - Analog Wiring Diagram with Equation of Winch Drum

135



$T_1 = L_1 - \Sigma r$; $T_\omega = \frac{L}{q}\Sigma$; $M_{c\bar{c}} = T_{\Omega_x} z_1 + T_{\Omega_z} x_1 + T_{R_x} z_c + T_{R_z} x_c$; $F_x = T_{R_x} - T_\omega \cos(\omega-\delta)$; $F_z = T_{R_z} + T_\omega \sin(\omega-\delta)$

Figure , , - Analog Wiring Diagram of Computation of Forces and Moments Caused by Line Tension and by the Cable Bending over the Ramp Door



1132 MACHINE

$$F_D \cos\phi + l W_c \sin\phi = I_c \ddot{\phi} \quad ; \quad F_c = W_c \cos\phi - F_D \sin\phi - l m_c \dot{\phi}^2$$

Figure 66 - Analog Wiring Diagram Showing Equation for Cargo Pendulum Effect

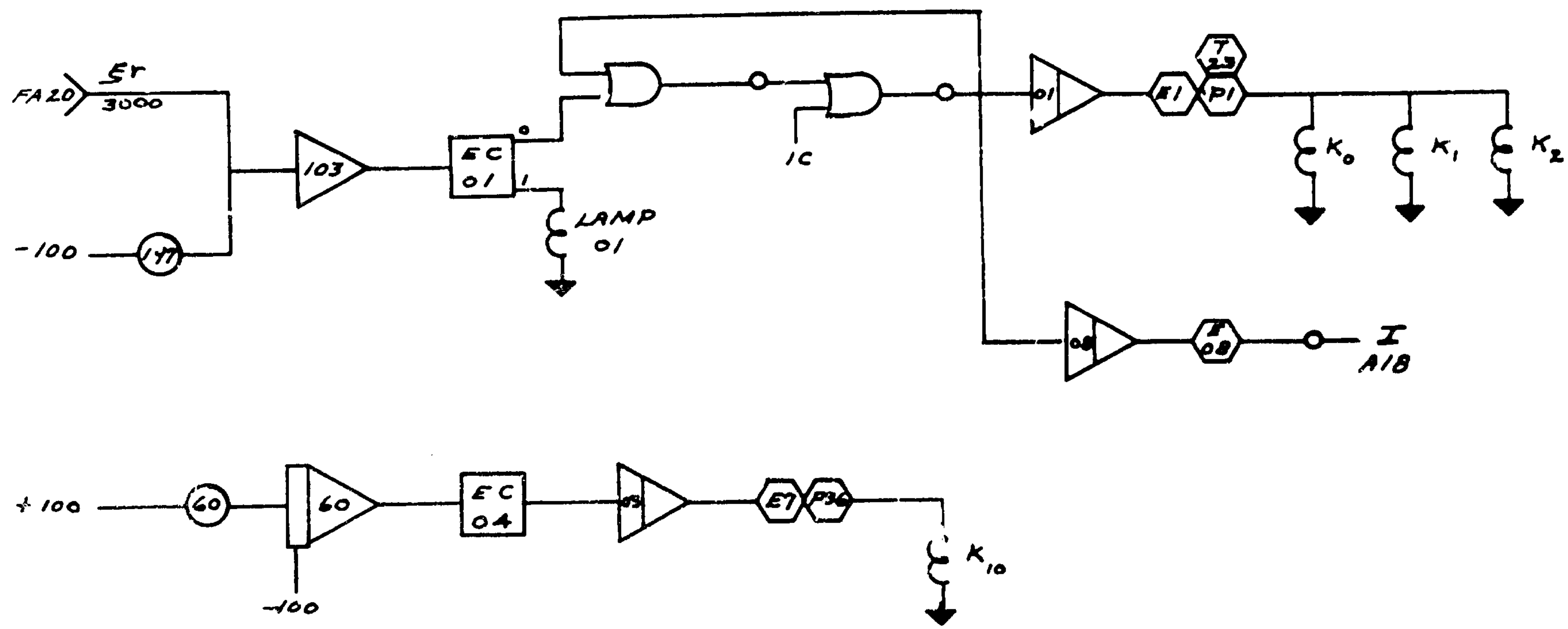


Figure 67- Analog Wiring Diagram of Winch Line Run-Out Detection Circuit
and Brake Release Timing Circuit

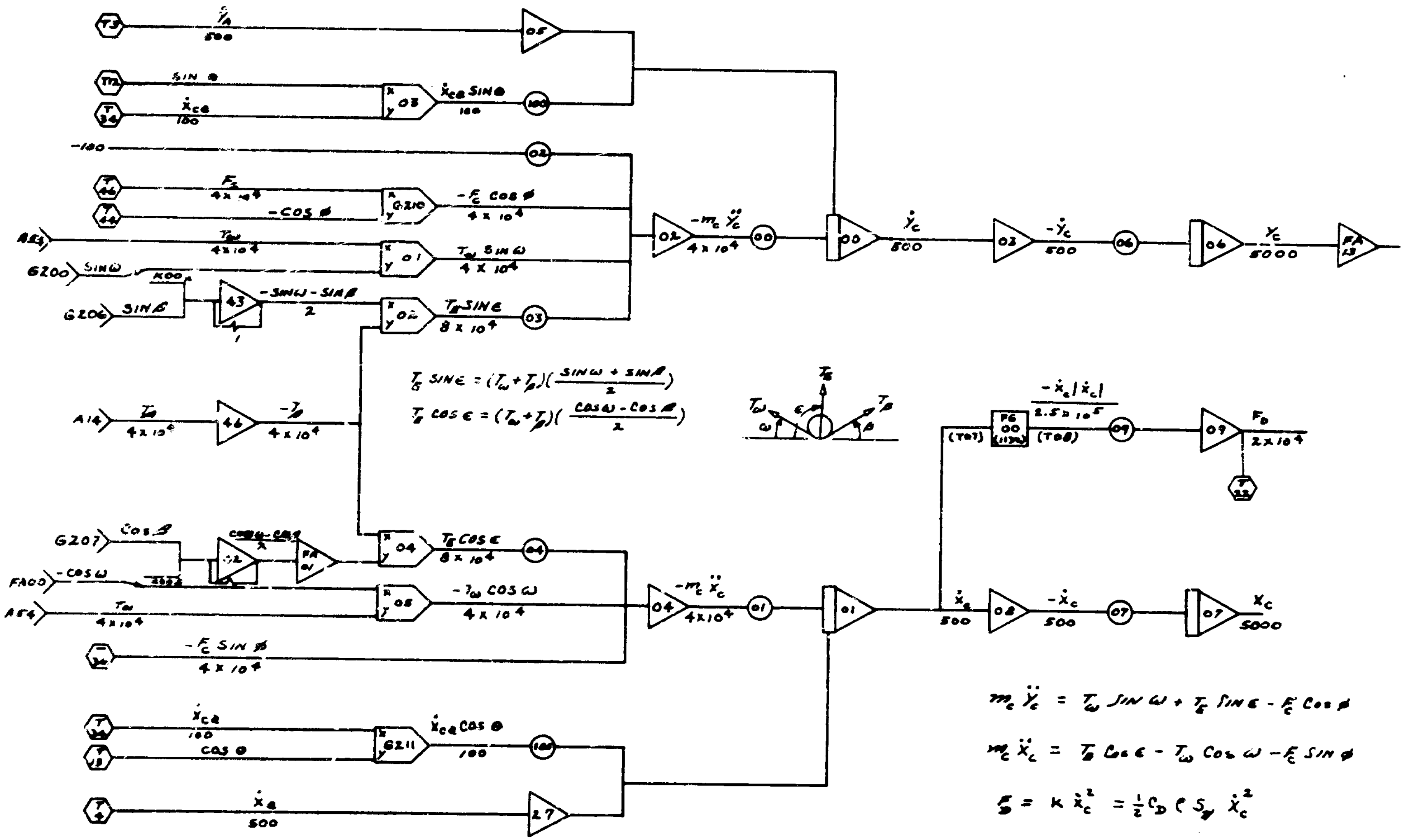
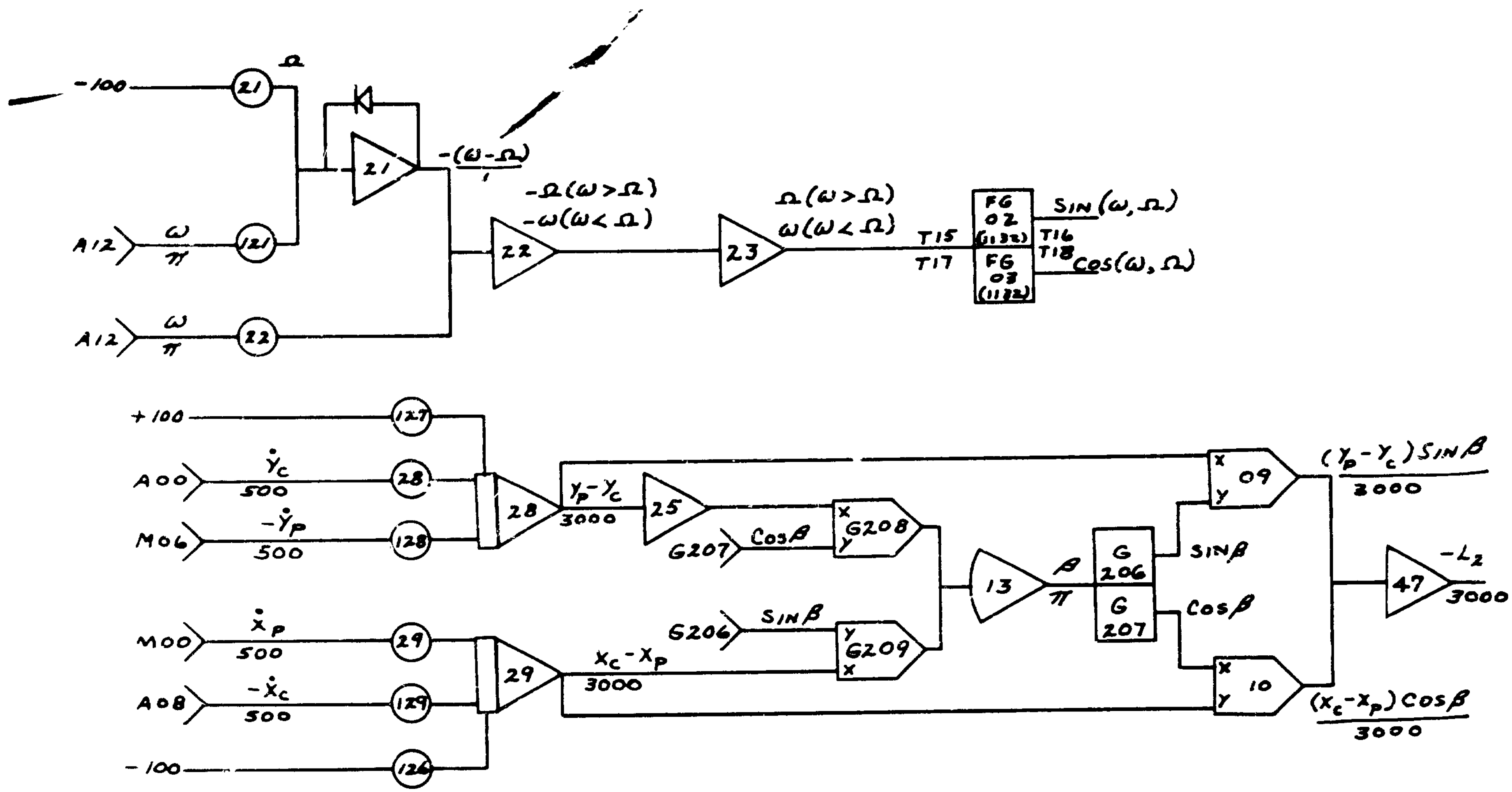


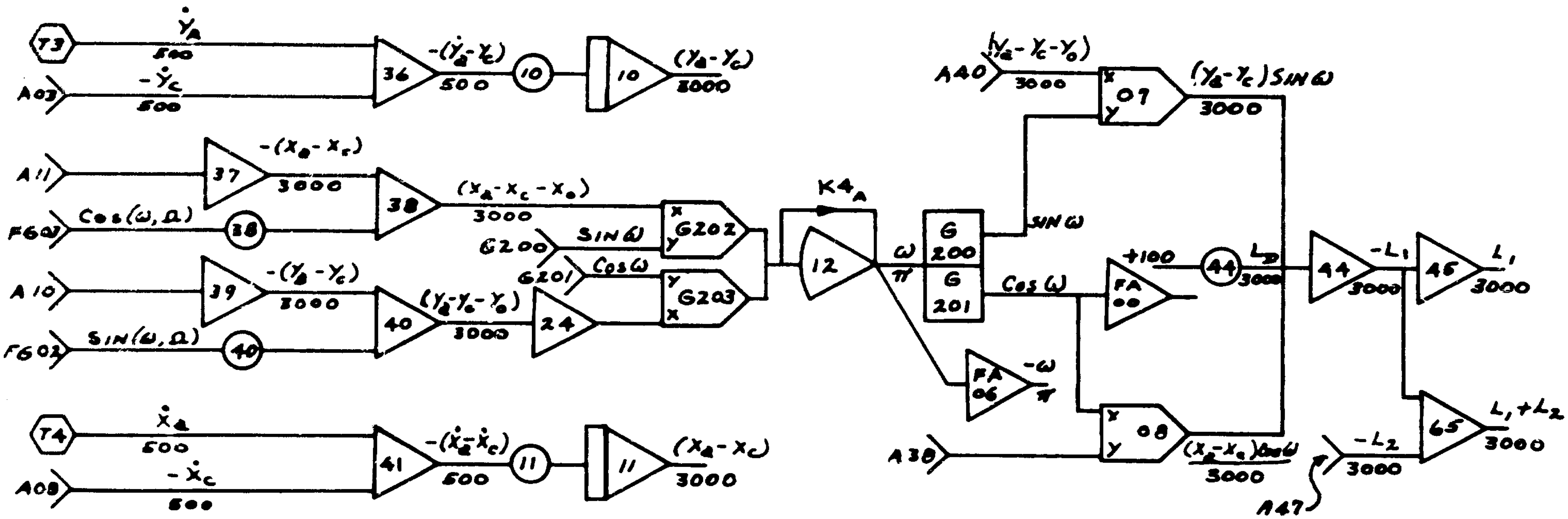
Figure 6[illegible] - Analog Wiring Diagram Showing Equations for Cargo Horizontal and Vertical Acceleration and Cargo Drag



$$(Y_p - Y_c)\cos\beta + (X_c - X_p)\sin\beta = 0$$

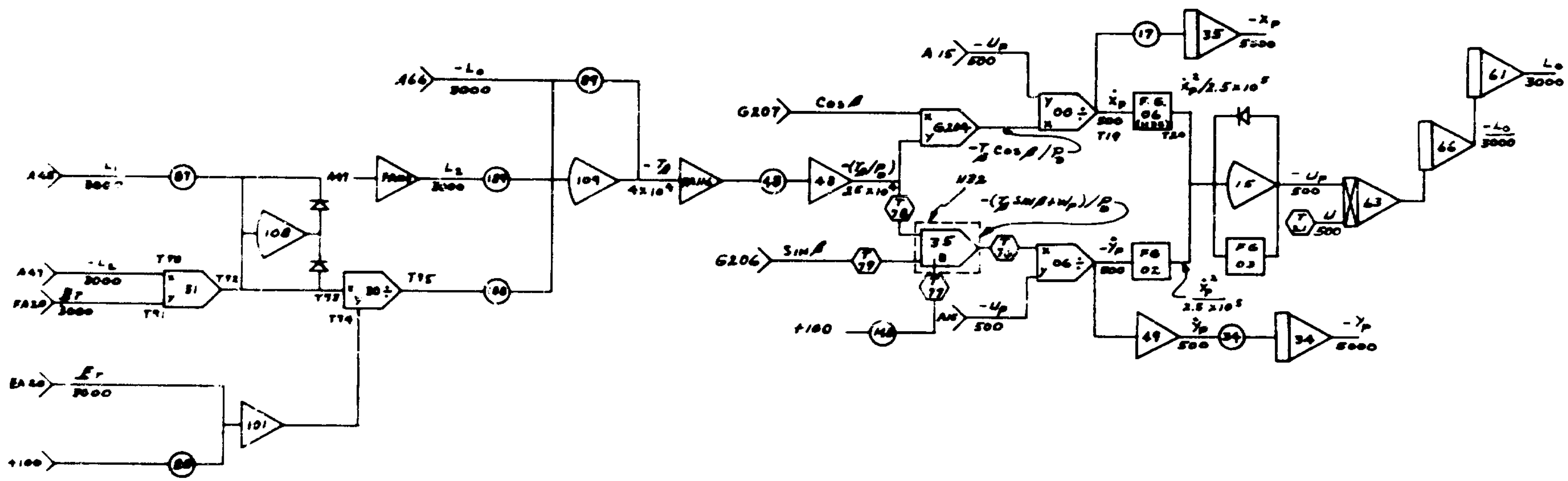
$$L_2 = (Y_p - Y_c)\sin\beta + (X_c - X_p)\cos\beta$$

Figure 69 - Analog Wiring Diagram Showing Computation of Angle and Line Length between Cargo and Parachute



$$(Y_a - X_c - X_o)\,\mathrm{SIN}\,\omega - (Y_a - Y_c - Y_o)\,\mathrm{COS}\,\omega = 0 \qquad L_1 = (X_a - X_c)\,\mathrm{COS}\,\omega + (Y_a - Y_c)\,\mathrm{SIN}\,\omega + L_D$$

Figure 7[illegible] - Analog Wiring Diagram Showing Computation of Angle and Line Length between Cargo and Airplane



BEFORE BRAKING $\quad T_B = K\left[\frac{L_2}{L_0} - 1\right]$

AFTER BRAKING $\quad T_B = K\left[\frac{L_1 + L_2 - (L_0 + E_r)}{L_0 + E_r}\right]$

$$U_p^2 = \dot{X}_p^2 + \dot{Y}_p^2$$

Figure 71 - Analog Wiring Diagram Showing Computation of Line Tension and Resultant Parachute Velocity

APPENDIX II

TECHNICAL INTEGRATION AND EVALUATION DATA

The material in this appendix was submitted to the Technical Integration and Evaluation (TIE) Contractor, Dunlap and Associates, Inc., One Parkland Drive, Darien, Connecticut, on 29 July 1966, in response to its report Information Requirements for Technical Integration and Evaluation of Low Level Airdrop Concepts, 22 April 1966. As such, it does not contain all the important data on the Trolley system nor does it necessarily show Trolley at its best advantage. More complete information is reported in the main body of this report.

TROLLEY SYSTEM DESCRIPTION

The Trolley system consists of a parachute trailing at the end of a long cable which passes through a slide on the drop cargo and onto a winch in the aircraft. A stop which cannot pass through the slide is attached to the cable between the drop cargo slide and the winch. When the winch brake is released, the drag of the parachute is applied to the slide by this stop, thus extracting the drop cargo from the aircraft.

For the first few seconds of drop, the cable between the drop cargo and the aircraft is allowed to pay out freely; the tension in that portion of the cable is minimal. The system in this phase is much like the extraction phase of a conventional paradrop.

After a predetermined amount of cable is payed out, the winch is quickly braked to a controlled stop, and the tension in both cable sections becomes approximately equal. Due to aerodynamic drag and the difference in line slopes, the slide from which the drop cargo is suspended begins to move toward the parachute while continuing to decelerate horizontally. When the drop cargo touches the ground, the slide is disconnected from the drop cargo by a standard impact release mechanism. A short time later, the slide is released from the cable when it strikes a stop placed on the cable about 10 feet from the parachute. The cable and parachute are then retrieved into the aircraft.

Figure [illegible] shows the Trolley drop sequence described above.

EVALUATION PARAMETERS

The parametric data requested by Dunlap are presented in Table X which uses the same symbols that appear in the previously mentioned Dunlap report.

Items 1, 2, and 3 assume the Trolley time sequences to be broken down as follows:

- T_1 Time from initiation of extraction until drop cargo is clear of aircraft
- T_2 Time from aircraft clearing until braking
- T_3 Time to stop winch
- T_4 Time from winch stopping until winch starts to reel-in
- T_5 Time from reel-in start until touchdown

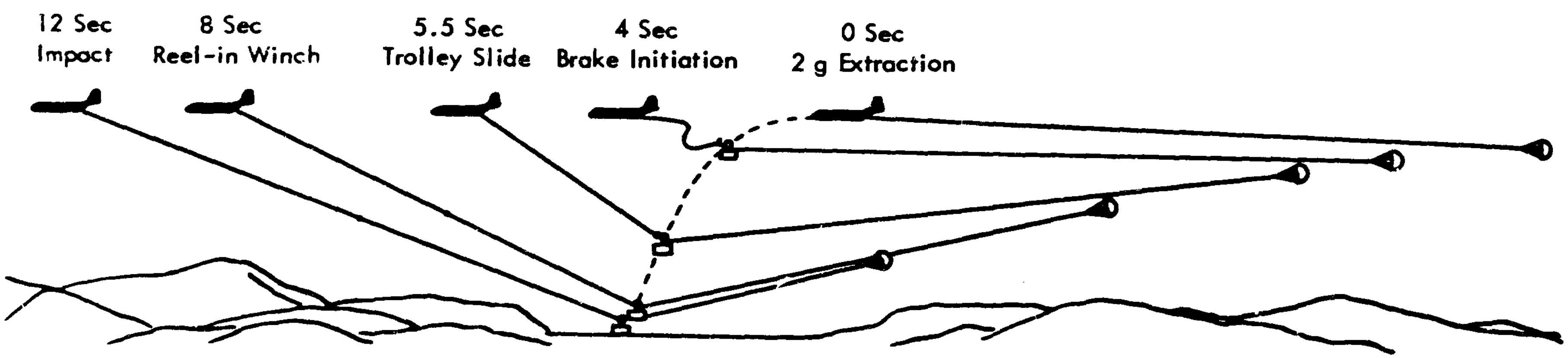


Figure 72 -- Drop Sequence

Load Parameter	General Cargo	M38A1 1/4-Ton Truck	M274 Weapons Carrier	105 MM Howitzer	M37 3/4-Ton Truck
1. Min T_1 (seconds)	1.2-	→			
Min T_2	3.3	→			
Min T_3	0.9	→			
Min T_4	1.4	→			
Min T_5	2.0	→			
2. Max T_1 (seconds)	1.2+	→			
Max T_2	3.3	→			
Max T_3	2.1	→			
Max T_4	2.6	→			
Max T_5	6.0	→			
3. Exp T_1 (seconds)	1.2	→			
Exp T_2	3.3	→			
Exp T_3	1.5	→			
Exp T_4	2.0	→			
Exp T_5	4.0	→			
4. Min T (seconds)	8.8	→			
5. Max T (seconds)	15.2	→			
6. Exp T (seconds	12.0	→			
7. F_e (pounds)	5750	7060	12,660	11,768	16,342
8. F_r (pounds)	5750	7060	12,660	11,768	16,342
9. V_v (fps)	2.0	4.5	7.5	8.0	9.0
10. V_h (fps)	25.5	29.5	39.0	41.0	44.0
11. ϕ (degrees)	9				
12. NA(1) = 3 aircraft					
NA(2) = 6 aircraft					

	Mixture 1	Mixture 2
13. Min CT (minutes)	16	16
14. Max CT (minutes)	22	22
15. Exp CT (minutes)	20	20

[illegible] - Numerical Drop Parameters

Items 1 through 10 are the same for single and multiple drops.

Item 11 shows the maximum impact angle.

Item 12 assumes the following:

Mixture 1: One aircraft makes three passes.

Two aircraft make two passes.

Mexture 2: Three aircraft make three passes.

Three aircraft make two passes.

Items 13 through 15 assume a "V" in trail formation as discussed in Section V of this memorandum. These cumulative drop times do not differ because only the first element of Mixture 2 makes three passes. Thus, the time is the same as for Mixture 1 since its first aircraft also makes three passes.

Figure 73 presents the time histories of the forces of Items 7 and 8. Each force time history is presented in "g" units and is the same for all drop loads. (Note that in Trolley airdrop the maximum retardation force on the drop cargo occurs at extraction.)

Table XI shows the items, listed in Table II on page 9 of the Dunlap Report, which Trolley can drop. All other Table II items are too heavy. It should be noted that the two drop mixtures are labeled Mixture 1 and Mixture 2.

Tables XII and XIII show how Mixtures 1 and 2, as listed on Dunlap's Table II, are spaced in a C-130 aircraft. These mixtures are not considered typical for an operational mission and may well lead to erroneous conclusions concerning the loading efficiency of a given drop system. More efficient loading will result when a larger total load is to be moved due to the greater number of load combinations possible. In an attempt to optimize the loading of Mixture 2, one change was made. The six general cargo loads were assumed to be composed of many small boxes. These boxes were rearranged to fit on four, 3750-pound, 8-foot platforms. Without this rearrangement, one more drop aircraft would be required.

Trajectories of the five individual items which Figure 3 shows that Trolley can drop are presented on Figure 74. The trajectory of the M37 truck dropped in a 15-knot, 45-degree crosswind is shown in Figure 75.

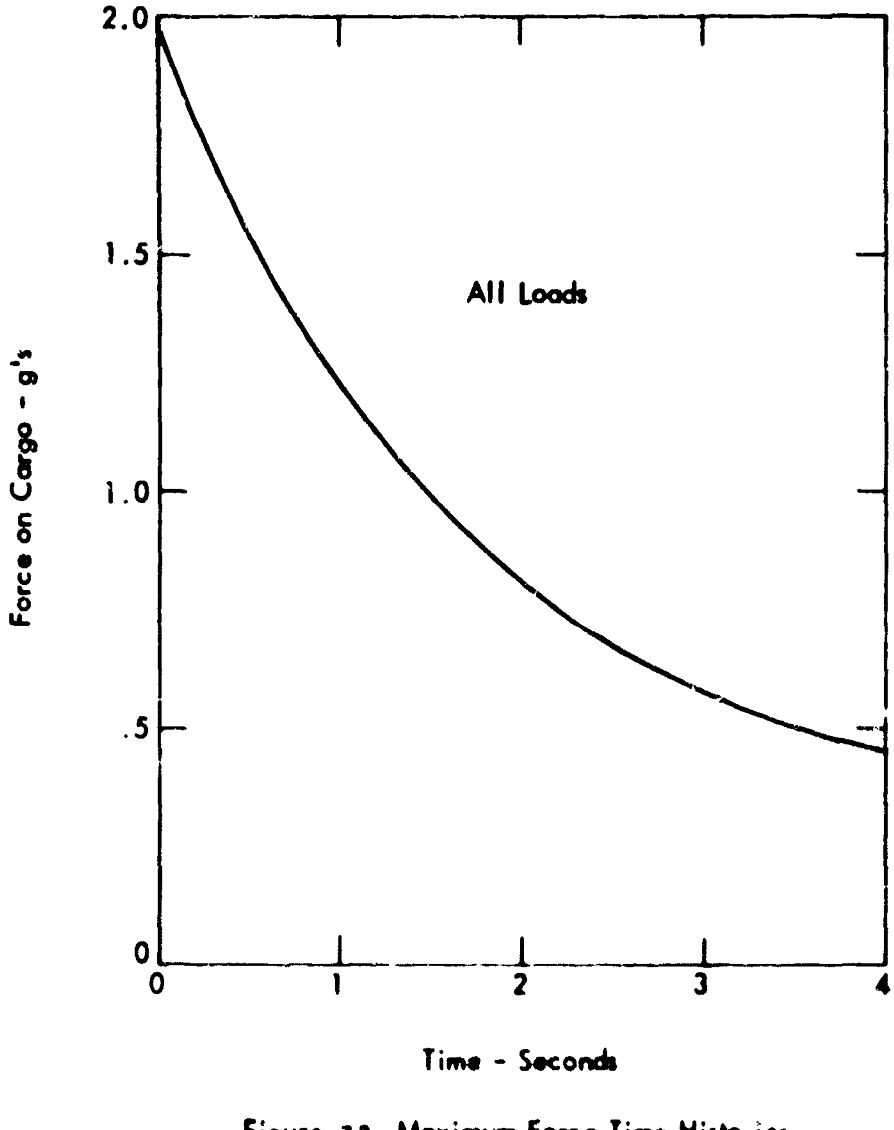


Figure 73- Maximum Force Time Histories

Item No.	Military Designation	Description	Weight	Rigged Weight for Trolley
1	-	General Cargo	2,500	2,875
2	M38A1	1/4-ton, 4 x 4 Utility Truck with 300-Pound Load	3,000	3,530
3	M274	Four 1/2-ton Infantry Light Weapons Carrier (Piggy-Back) with 14 Boxes of 105 mm Ammo	5,280	6,330
4	105 mm Howitzer	Plus Accessories	5,236	5,884
5	M37	3/4-ton Cargo Truck with 2400-Pound Load	7,187	8,171
9	Mixture 1	Two No. 1, Four No. 2, Two No. 3	27,560	32,530
10	Mixture 2	Six No. 1, Four No. 2, Four No. 4, Four No. 5	76,692	87,590

Table XI- Drop Items

AIRPLANE NO. 1	Length of Cargo Compartment Used
Trolley Winch	4'
	1-1/2' space
One M274	9-3/4'
	1' space
One M274	9-3/4'
	26'

Two general cargo loads on ramp door (one platform)

AIRPLANE NO. 2	
Trolley Winch	4'
	1-1/2' space
One M38A1	12'
	1' space
One M38A1	12'
	30-1/2'

AIRPLANE NO. 3	
Trolley Winch	4'
	1-1/2' space
One M38A1	12'
	1' space
One M38A1	12'
	30-1/2'

Table XII - Aircraft Loading Diagram - Mixture 1

	Length of Cargo Compartment Used
Airplane No. 1 & 2	
Trolley Winch	4'
	1' space
One 105 mm Howitzer	16'
	1/2' space
One 105 mm Howitzer	16'
	37-1/2'
One cargo (4500 lb unrigged / 5000 lb rigged) on ramp door	
Airplane No. 3 & 4	
Trolley Winch	4'
	1/2' space
One M38A1	12'
	1/2' space
One M38A1	12'
	1/2' space
One cargo (3000 lb unrigged / 3400 lb rigged)	8'
	37-1/2'
Airplane No. 5 & 6	
Trolley Winch	4'
	1' space
One M37	16'
	1/2' space
One M37	16'
	37-1/2'

All aircraft make three passes over the drop zone in a V in-trail formation with 3 aircraft in each V. On the last pass, aircraft numbers 5 and 6 make no drop.

[illegible] - Aircraft Loading Diagram - Mixture 2

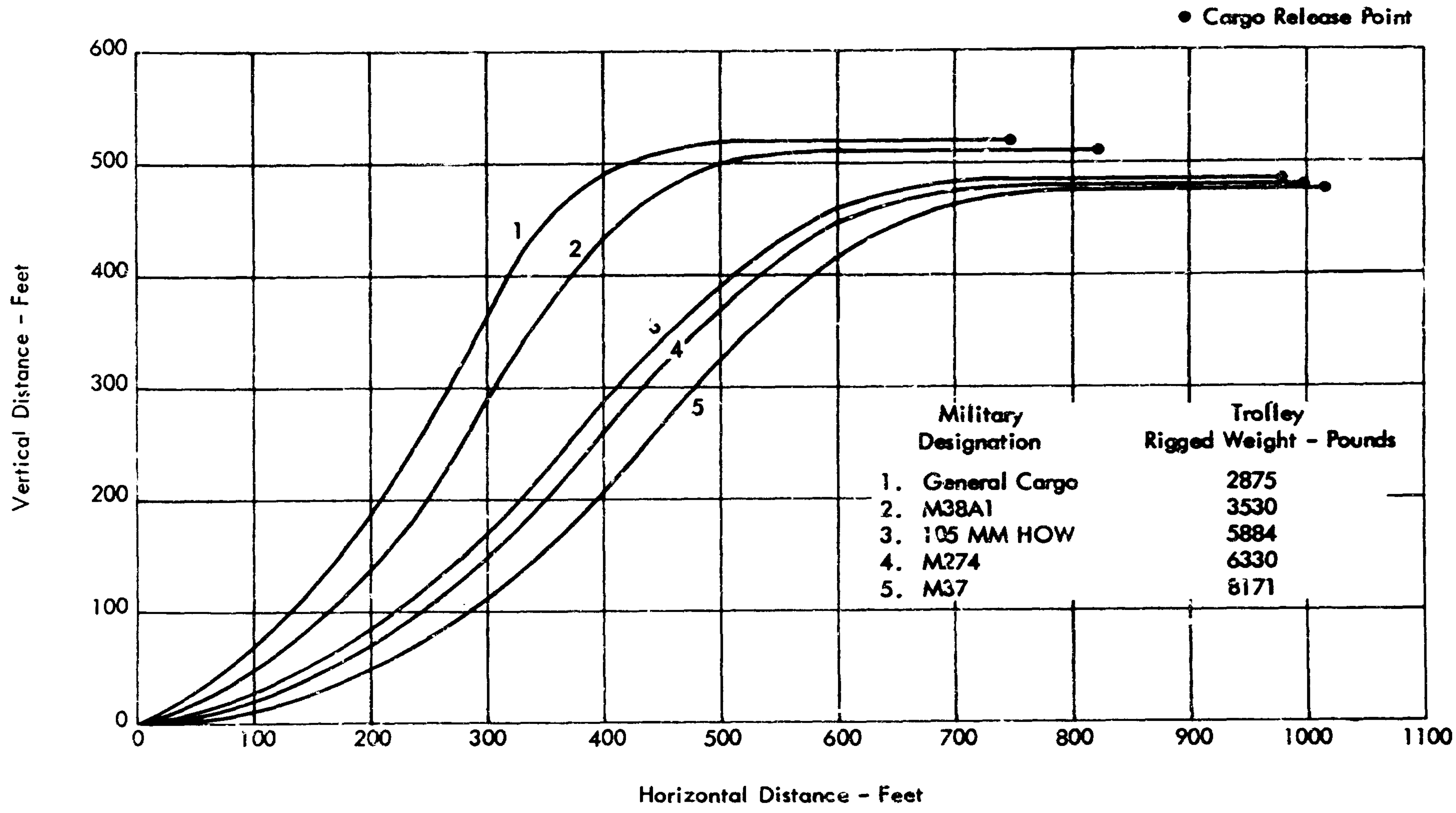


Figure 74 - Drop Trajectories, Five Drop-Items

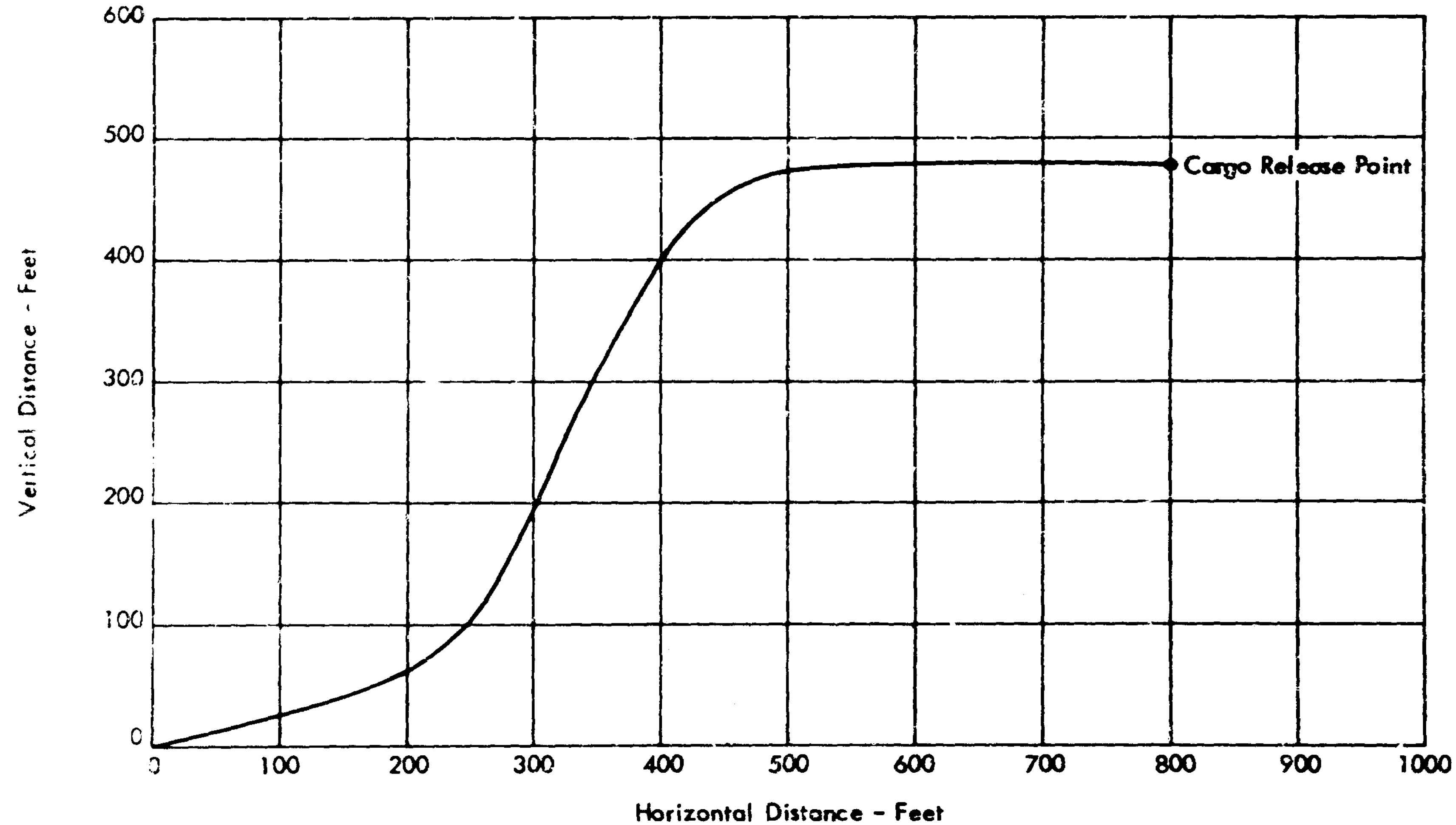


Figure 75- Drop Trajectory, M37 in Crosswind

Figure 76 presents trajectory of the maximum, 5000 pounds, that can be dropped by Trolley on a drop zone with an altitude of 5000 feet and a temperature of 100°F. The trajectory of the M37 under these conditions, which was requested by Dunlap, could not be presented because the drop load is too heavy for Trolley using a C-130 aircraft.

Figure 77 presents the trajectory envelope of the M37 dropped at standard conditions. The limits of this envelope are defined by the maximum errors which can be expected in the drop parameters. Since the M37 is also the heaviest item on Dunlap's Table II which can be dropped, no other trajectory envelopes are shown.

COMPATIBILITY WITH C-141A

Review of C-141A performance data at a gross weight of 210,000 pounds and a speed of 120 knots indicates that approximately 40,000 pounds of excess thrust is available at sea level and standard atmospheric conditions. A 20,000-pound unit drop weight is the maximum that can be delivered by C-141A with the Trolley system based on a 2.0 g extraction. For a 5000-foot standard atmosphere drop zone altitude, the unit drop weight is reduced to 16,000 pounds based on approximately 32,000 pounds of excess thrust available.

FORMATION FLYING

Formation flying is possible either with a simple in-trail formation or with a standard "V" formation with a spacing of 2000 feet between elements. Eliminating the requirement for each succeeding element within a section to stack 100 feet above the preceding element is necessary. Altitude control is included in the random error analysis and found to be one of the most significant variables. Thus, formation drop altitude is dictated by the loads to be dropped.

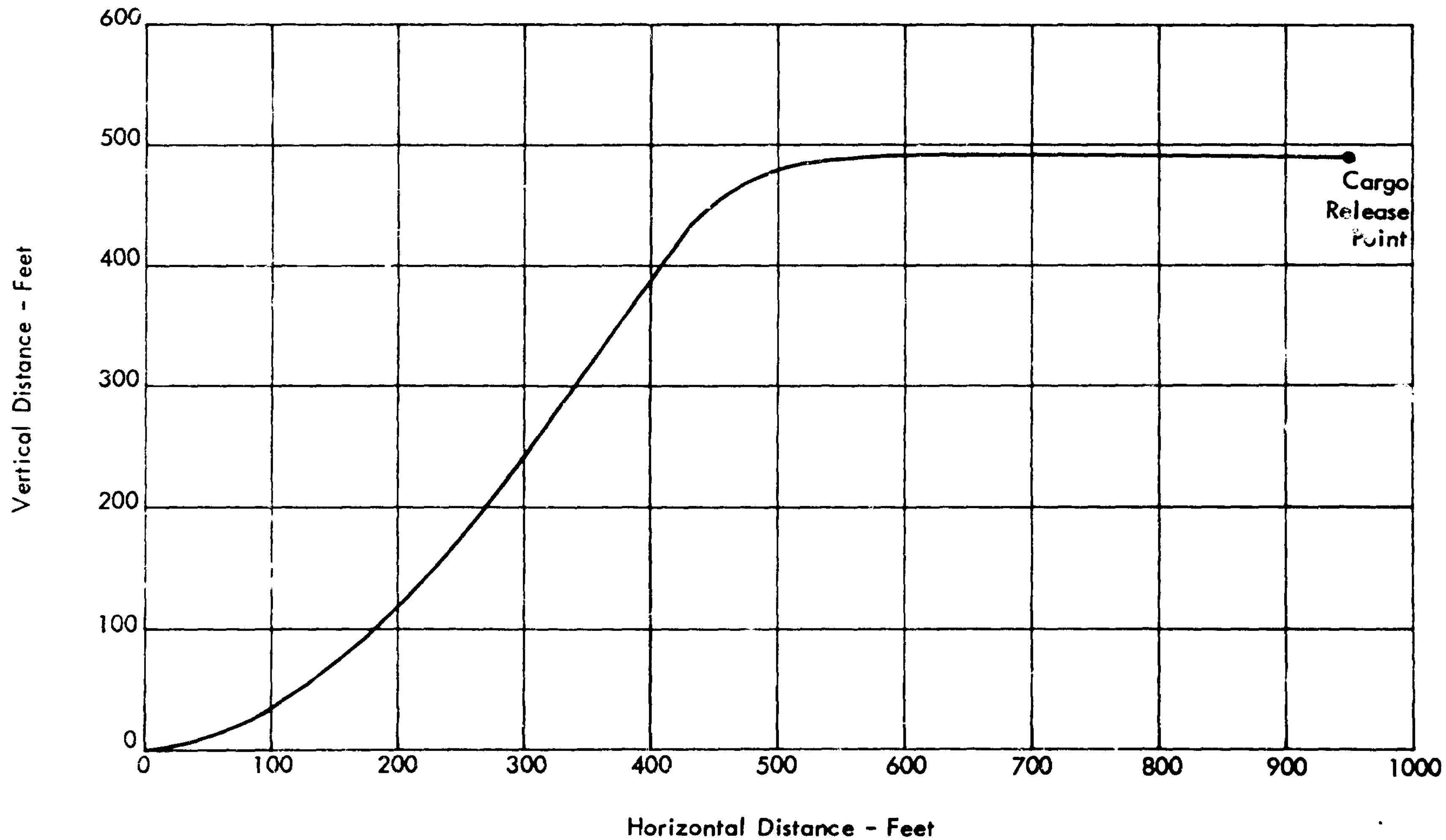


Figure 76 - Drop Trajectory, Maximum Weight at 5000 Feet

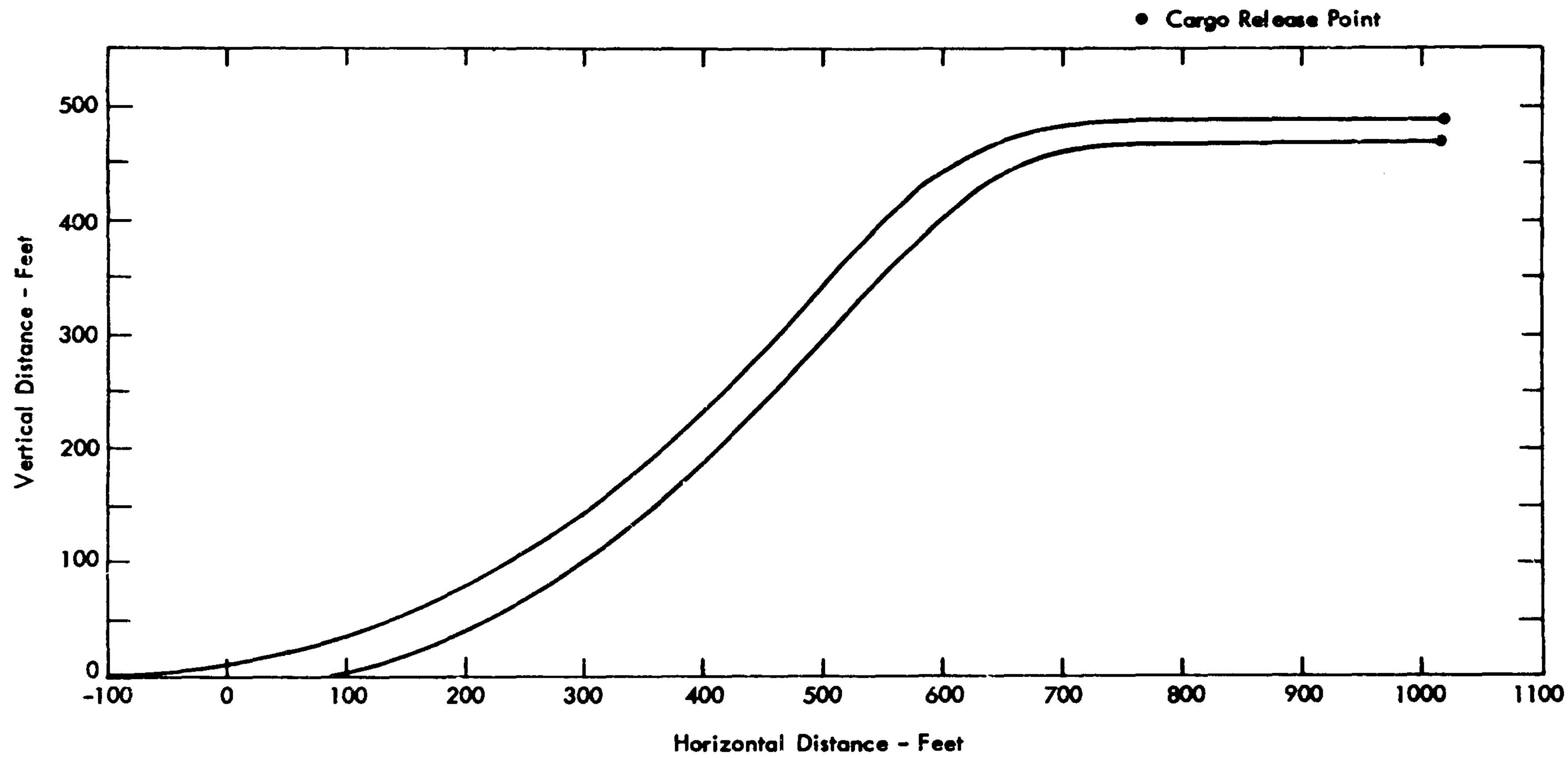


Figure 77 - Drop Trajectory Envelope, M37

COMPATIBILITY WITH PERSONNEL DROPS

An analysis was made to determine the Trolley System compatibility with personnel drops. This analysis was based on the assumption that a personnel parachute system, similar to the T-10, can be developed to operate safely from a drop altitude of 500 feet.

Exit through the paratroop door or over the cargo door ramp results in the parachute falling directly in line behind the aircraft. Paradrop of personnel is possible when sufficient vertical and/or horizontal clearance is provided between the Trolley cable and the paratrooper descending with the T-10 parachute. Since horizontal displacement of the parachute would be difficult under some conditions, all clearance must be provided in the vertical plane passing through the cable. The T-10 parachute trajectory is such that it falls 120 feet in 2.7 seconds and then assumes a constant rate of descent of 15.4 feet per second with a 250-pound paratrooper. This path would pass through the Trolley cable position shortly after exit, and no personnel drop is possible when the cable and drag chute are being towed behind the aircraft with the normal 5.2-degree depression angle.

During the Trolley system load delivery sequence, however, the cable is depressed from its normal position sufficiently to provide adequate vertical clearance between the cable and personnel parachute. Sufficient clearance is provided from 4.2 seconds elapsed time from load extraction to 14 to 16 seconds at which time the cable and drag parachute return to the normal 5.2-degree trailing position.

If a parachutist jumped 1.4 seconds after the load is released, his T-10 parachute would complete its horizontal deceleration in an additional 3.2 seconds. At this point he would be 330 feet behind the aircraft and separating from it at the constant rate of 206 feet per second. About 6.4 seconds later (11 seconds elapsed time), the parachutist would be 1670 feet behind the aircraft and completely clear of the 1664-foot long cable trailing beneath him.

Thus personnel drops are compatible with the Trolley System. A paratrooper could jump as early as shown in the analysis above or could delay his jump until 4 to 6 seconds after load release and still be clear of the trailing cable. The total number of personnel which could be airdropped can be determined after a flight test program defines the time needed for the cable and drag parachute to return to the normal trailing position.

MECHANICAL RELIABILITY

A reliability analysis of the Trolley system, conducted to assess the reliability level inherent in the proposed conceptual design, is based on one complete operation of the system with the delivery of a single drop cargo to a pre-selected drop zone. A failure is defined to be any malfunction which results in failure to deliver the payload in a useable condition. A reliability level of 0.9997 is predicted for the proposed Trolley system based on the above ground rules. This prediction includes equipment presently installed in the C-130 aircraft which are specifically utilized during Trolley airdrop operation but are not peculiar to the Trolley system. It is assumed, however, that all other airborne equipment will function properly during the airdrop operation.

Predicted reliability values for individual equipment are shown in Table [illegible]. These values are based on experience with similar components from 27,832 flight hours of C-141 operational data; data from HC-130H test programs; and engineering judgment.

Nomenclature	Failures/10^6 System Operations	Predicted Reliability
Winch	200	0.9998
Winch Control	20	0.99998
Cable	1	0.999999
Trolley Assembly*	3	0.999997
Cable & Trolley Guide Rail	1	0.999999
Drag Parachute	1	0.999999
Cargo Tiedowns; Slings, and Extraction Lines	3	0.999997
Pendulum System	48	0.999952
Sighting Device	1	0.999999

*Includes functional redundancy

Table XXIV - Mechanical Reliability Predicted Values

The high reliability level predicted for the Trolley system can be attributed to the short duration of the airdrop operation and to the fact that the system is composed primarily of mechanical equipment which has historically demonstrated high levels of reliability. The system does, however, contain hardware which is not available "off-the-shelf." Further development of this equipment must ensure that good reliability design practices are adhered to if a high level of reliability for the system is to be achieved.

The reliability analysis indicates that the winch is potentially the primary reliability problem area in the system. In general, experience with winches in aircraft applications such as the HC-130H program indicates that the principal problems are created by the fact that winches are predominantly designed for industrial applications. Thus, the problems associated with the high-strength, light-weight requirements of aircraft applications are frequently neglected even with winches designed to aircraft specifications. Experience has also shown that this general problem can be overcome by adequate reliability monitoring and control during winch design and development.

More specific reliability problems are expected to arise from the braking and reel-in rate requirements. Although landing gear braking hardware (such as that found on B-52 aircraft) can be used for braking the winch, the reliability state-of-the-art for such systems has been unsatisfactory, historically. This potential problem area has been lessened somewhat since it was found that increased braking times (from 0.5 to 1.5 seconds) are permissible within the operational concept of the system. The reel-in rate requirement against the expected tensile loads imposes an unusually high-power requirement for the winch. This requirement, as well as other considerations, makes the use of a direct electrical or hydraulic drive for the winch very difficult. Use of a flywheel to store energy until reel-in is required would preclude the requirement to add an electric or hydraulic power source to the aircraft system to power the winch. This simplification will make the winch reliability goals easier to meet.

The winch control panel is not expected to be a reliability problem due to its relative simplicity. It is assumed that the control panel will consist of a simple timing device and associated control equipment and will not include more sophisticated capability such as cable tension sensing devices or automated input of aircraft flight parameters.

The Trolley slide assembly is expected to be highly reliable due to the basic simplicity of the assembly and functional redundancy in the drop cargo release mechanism.

The remaining hardware peculiar to the Trolley system is essentially mechanical in nature. Employment of standard reliability practices, such as derating and the use of high-reliability parts will ensure a high inherent level of reliability for these parts.

HUMAN RELIABILITY

Since a thorough evaluation of the human element in the Trolley system would require a relatively complete design of the hardware involved and the step-by-step rigging procedure, a detailed analysis of human reliability was not possible within the scope of the current study. However, a general review of the rigging deleted from the present systems and types of personnel needed to operate the system should give an indication of the degree of simplification afforded by the Trolley system.

Analysis of Trolley system requirements for preparation of rigging of platforms and drop cargo indicate the following may be accomplished:

Deletions

- Honeycomb as energy dissipator
- Adhesive for honeycomb
- Extraction parachute for each drop cargo unit
- Cargo parachute(s) and parachute platform for each drop cargo
- Parachute riser extensions
- Extra cargo parachute release (with multiple cargo parachutes)

Additions

- Four cargo slings per unit drop
- Second extraction line

The honeycomb as an energy dissipator may be eliminated due to low vertical impact velocity (maximum 9.5 fps). Elimination of honeycomb will lower the vertical center of gravity location 3 to 9 inches depending on the payload to be airdropped.

Individual extraction and cargo parachutes may be eliminated since their function is performed by the Trolley system. Additional rigging is also deleted as shown in Section XI of this memorandum.

For airdropping with the Trolley system, the platform is prepared according to T. O. 13C7-1-5/TM 10-500. Elimination of honeycomb, extraction and drop cargo parachutes, and some plywood requires repositioning of vehicles and recomputation of the platform center of gravity. Lashing procedures for individual vehicle and mass loads remain basically the same as outlined in applicable Army Technical Manuals 10-500. Use of static lines similar to those employed for extraction and cargo parachutes with current airdrop systems remains the same

for Trolley. Use of time delay cartridges (approximately 10 seconds) with cargo parachute releases will be continued. Dual extraction lines attached to the Trolley assembly suspension points would be utilized to preclude exceeding the limit load capacity of 1.5 times the gross rigged weight. Attachment of dual extraction lines to vehicle loads will be similar to that in TM10-500 for the M151, 1/4-ton utility truck equipped with shackles or pintels. The capacity of the airdrop cargo suspension slings will be doubled in strength by use of two slings per suspension point or a greater number of loops per sling.

Elimination of individual extraction and cargo parachutes, honeycomb, and plywood greatly reduces the unit airdrop weight, cost per pound of drop cargo delivered, parachute inventory, unit rigging time, and the number of parachute-rigger and aerial port squadron personnel. A loadmaster assistant (total airdrop crew of 3), will be required for multiple-pass/single-drop Trolley airdrops for duties similar to those performed during current PLADS AND LAPES airdrops per AFM 55-130. The overall skill level required will remain the same. The number of parachute rigger personnel will be reduced and loadmaster personnel requirements will increase. Aircrew personnel (pilot, copilot, and navigator) will require no additional formal training.

Due to the simplification inherent in the Trolley system, an increase in human reliability over the present system can be expected.

SENSITIVITY ANALYSIS

The sensitivity analysis was conducted by using a total system approach. Those variables which exert significant influence on horizontal impact velocity, vertical impact velocity, and airdrop altitude were isolated to determine their individual effects on these three parameters. These variables follow:

- o Aircraft Velocity
- o Unit Drop Weight
- o Parachute Drag
- o Parachute Vertical Position
- o Initial Cable Length
- o Cable Length at Braking
- o Time for Braking

Results of this analysis are presented in Figures 11 through 17. Plotted on the abscissa of each figure is one of seven variables listed above; plotted on the ordinate are the following three parameters:

- o Horizontal Impact Velocity
- o Vertical Impact Velocity
- o Airdrop Altitude

All curves presented in the sensitivity analysis are subject to the following conditions:

o Aircraft Velocity	130 knots
o Unit Drop Weight	10,000 pounds
o Initial Cable Length	1300 feet
o Cable Length at Braking	1650 feet
o Parachute Position	5-degree depression angle
o Braking Time	1.5 seconds
o Parachute Drag	20,000 pounds
o Sea Level Standard Day	–

The above conditions are the worst case for Trolley since the unit drop weight is 10,000 pounds (maximum for Trolley using a C-130). The aircraft velocity also approaches a maximum for Trolley for reasonable impact velocities. Much lower horizontal velocities occur with a reduction in aircraft velocity. At an aircraft velocity of 110 knots, the horizontal impact velocity for a 10,000-pound drop cargo is about 15 feet-per-second. At 120-knot aircraft velocity, the horizontal impact velocity is about 25 feet per second.

Figure 78 shows that vertical impact velocity changes very little with aircraft velocity error. Horizontal impact velocity and drop altitude, however, each change measurably with aircraft velocity variations. It should be noted that all three variables plotted on the ordinate assume lower values at the lower aircraft velocities. Hence one can conclude from the mathematics of the system as well as intuitive logic that lower impact velocities and lower drop altitudes result at the lower aircraft velocities.

Figure 79 shows that the Trolley system is essentially insensitive to unit drop weight within the range of weights shown on the abscissa of that figure. The variation of $\pm$ 500 pounds in the unit drop weight (10,000 pounds) amounts to a $\pm$ 5 percent error allowable in determining that weight.

The error in parachute drag affects the impact velocities and drop altitude as shown in Figure 80. Since parachute drag is the force which extracts the drop cargo, the initial error in parachute drag is directly proportional to an error in extraction acceleration. In this sensitivity analysis, the error of $\pm$ 1000 pounds in parachute drag amounts to $\pm$ 5.0 percent of the total drag of 20,000 pounds. This also amounts to $\pm$ 5.0 percent error in extraction acceleration or $\pm$ 0.1 g error in the nominal 2.0 g extraction. The drop altitude is measurably affected by this source of error, but impact velocities are relatively insensitive.

Horizontal impact velocity and drop altitude are sensitive to parachute vertical position while vertical velocity appears to be insensitive to the parachute position as shown in Figure 81. Actually, the increase in drop altitude with lower initial parachute position allows for a longer time for vertical velocity to be arrested. If drop altitude were held constant, then vertical velocity would show essentially the same sensitivity to parachute position, but horizontal velocity would be higher. The range of parachute positions investigated ($\pm$ 20 feet) amounts to about $\pm$ 17 percent of the parachutes nominal distance below the airplane.

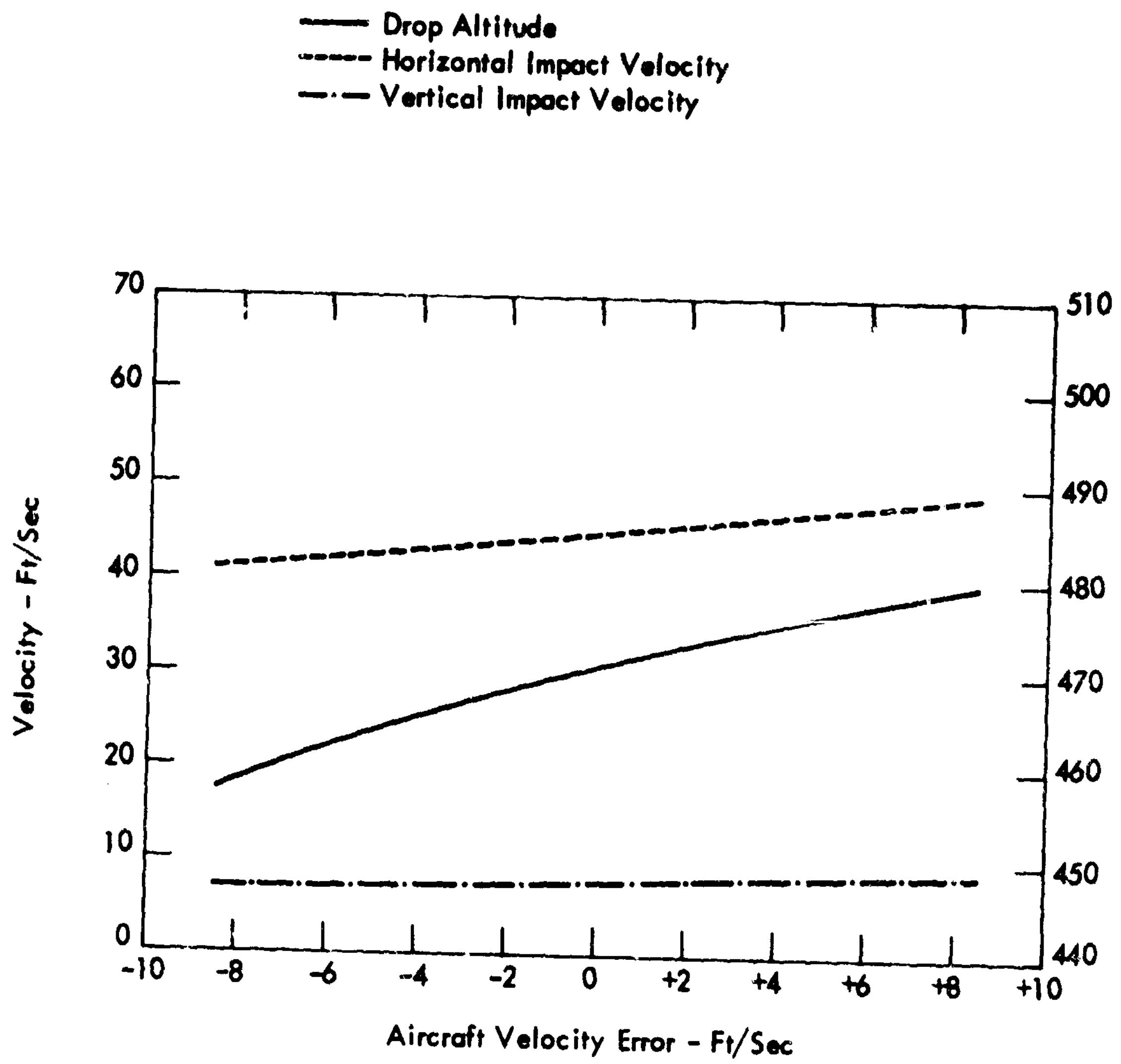


Figure 78 – Sensitivity to Aircraft Velocity

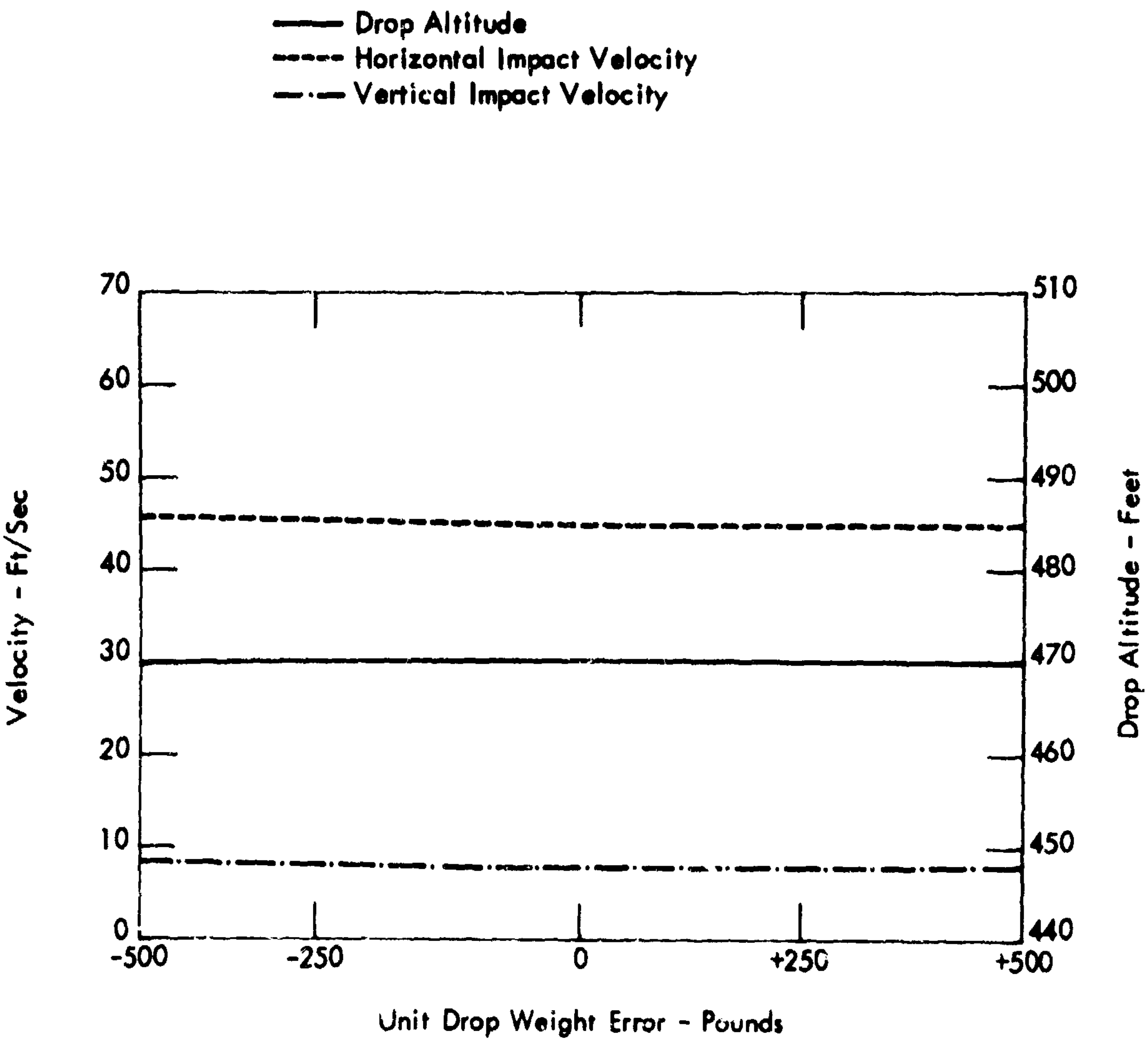


Figure [illegible] - Sensitivity to Unit Drop Weight

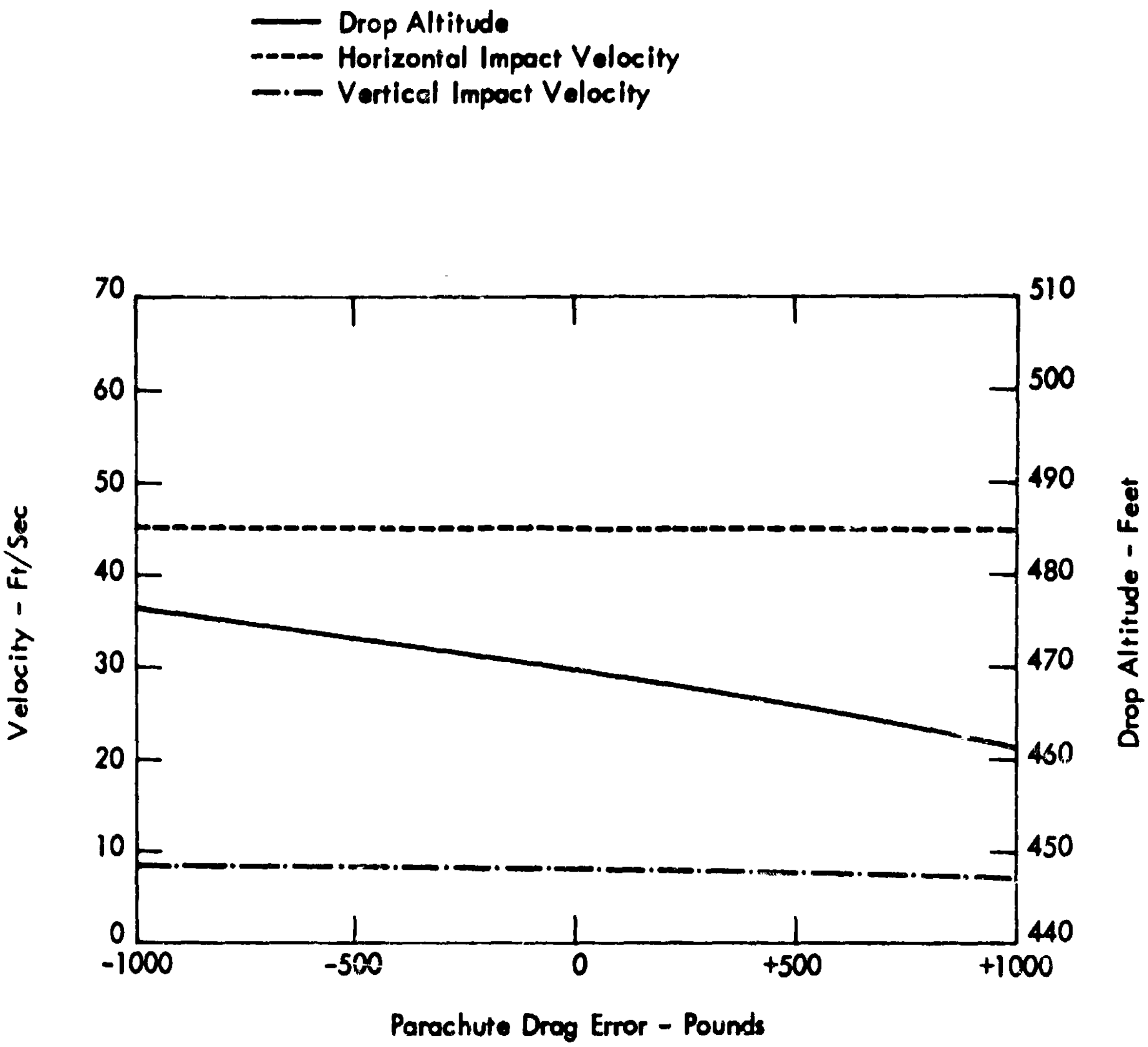


Figure 80 - Sensitivity to Parachute Drag

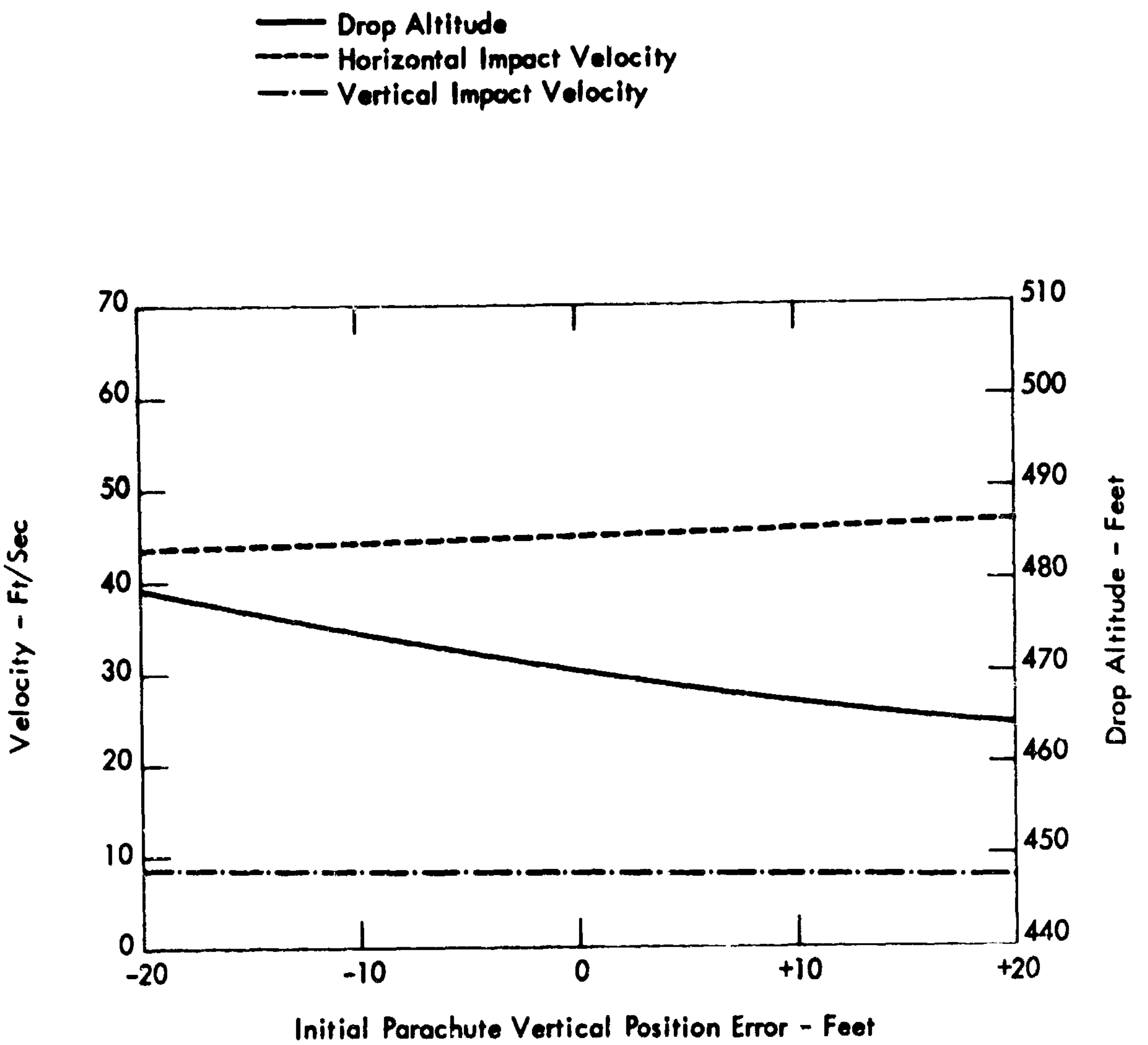


Figure 81 - Sensitivity to Parachute Vertical Position

The initial cable length payout of 1300 feet is one variable that should be subject to very little error since its measurement is simple and accurate. An error of ± 25 feet or 1.9 percent of cable payout has only slight effect on drop altitude and essentially no effect on impact velocities as shown in Figure 82.

The amount of cable payed out during free fall added to the initial line length amounts to the cable length at braking. As seen in Figure 83, horizontal impact velocity is higher for the shorter payout lengths, and drop altitude is affected in the opposite manner. Vertical velocity shows a continuing increase with additional cable payout. The range of error investigated was ± 40 feet or 2.4 percent of cable length at braking. Again this is a variable that should be subject to little error.

The braking time error of ± 0.6 second shown in Figure 84 amounts to ± 40 percent of the nominal 1.5-second braking time. This large possible error was investigated because of the degree of uncertainty concerning repeatability of stopping time for the brake. Fortunately the Trolley system performance is affected only slightly by this relative large error.

In Figure 85 the horizontal and vertical impact velocity variations with drop altitude are shown. The altitude error shown is ± 20 feet or ± 4 percent of the nominal 500-foot drop altitude. This error change is well within current state of the art radar altimeters accuracies.*

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*See Operational Analysis and Cost Paragraphs.

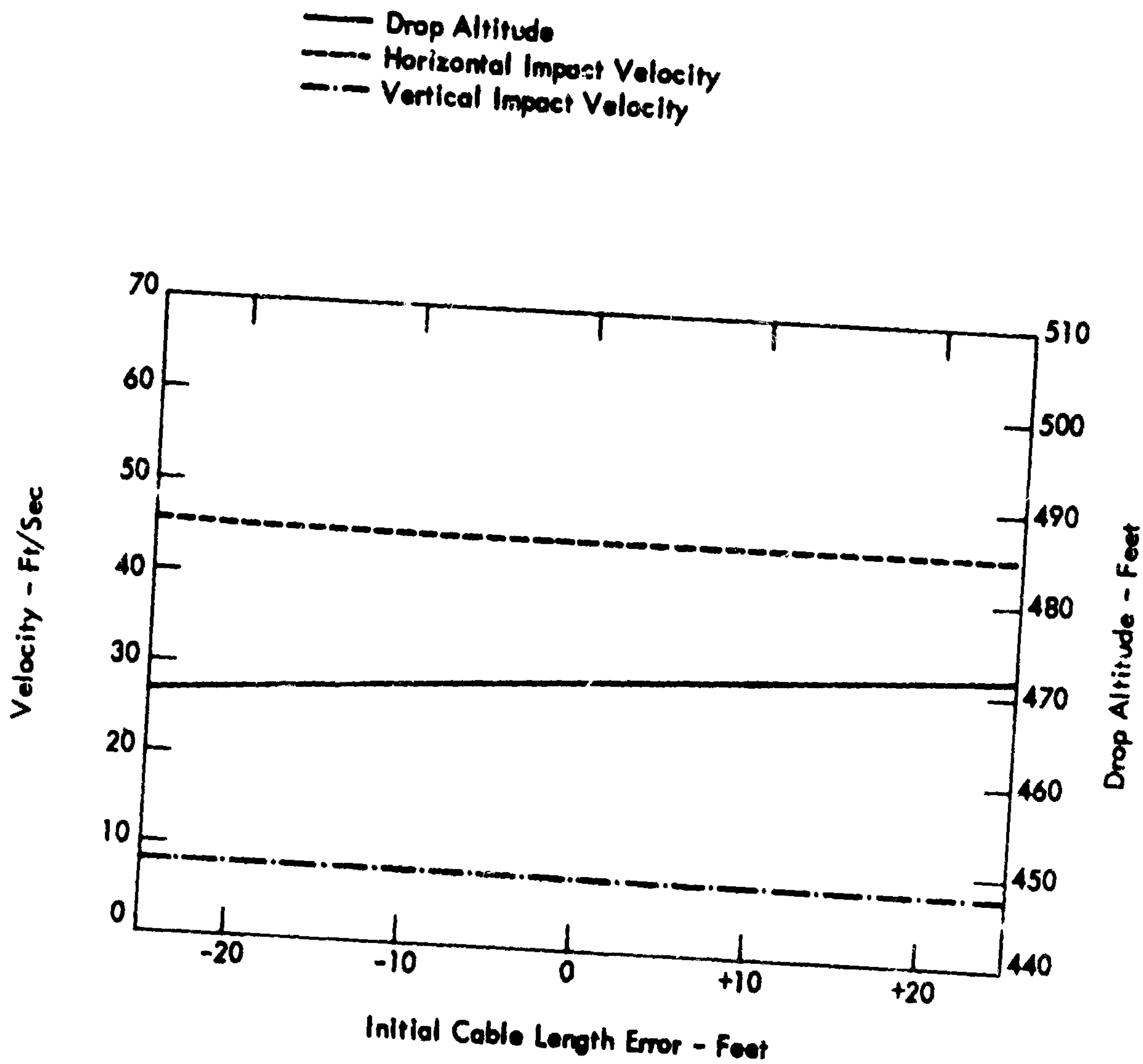

Figure 82 - Sensitivity to Initial Cable Length

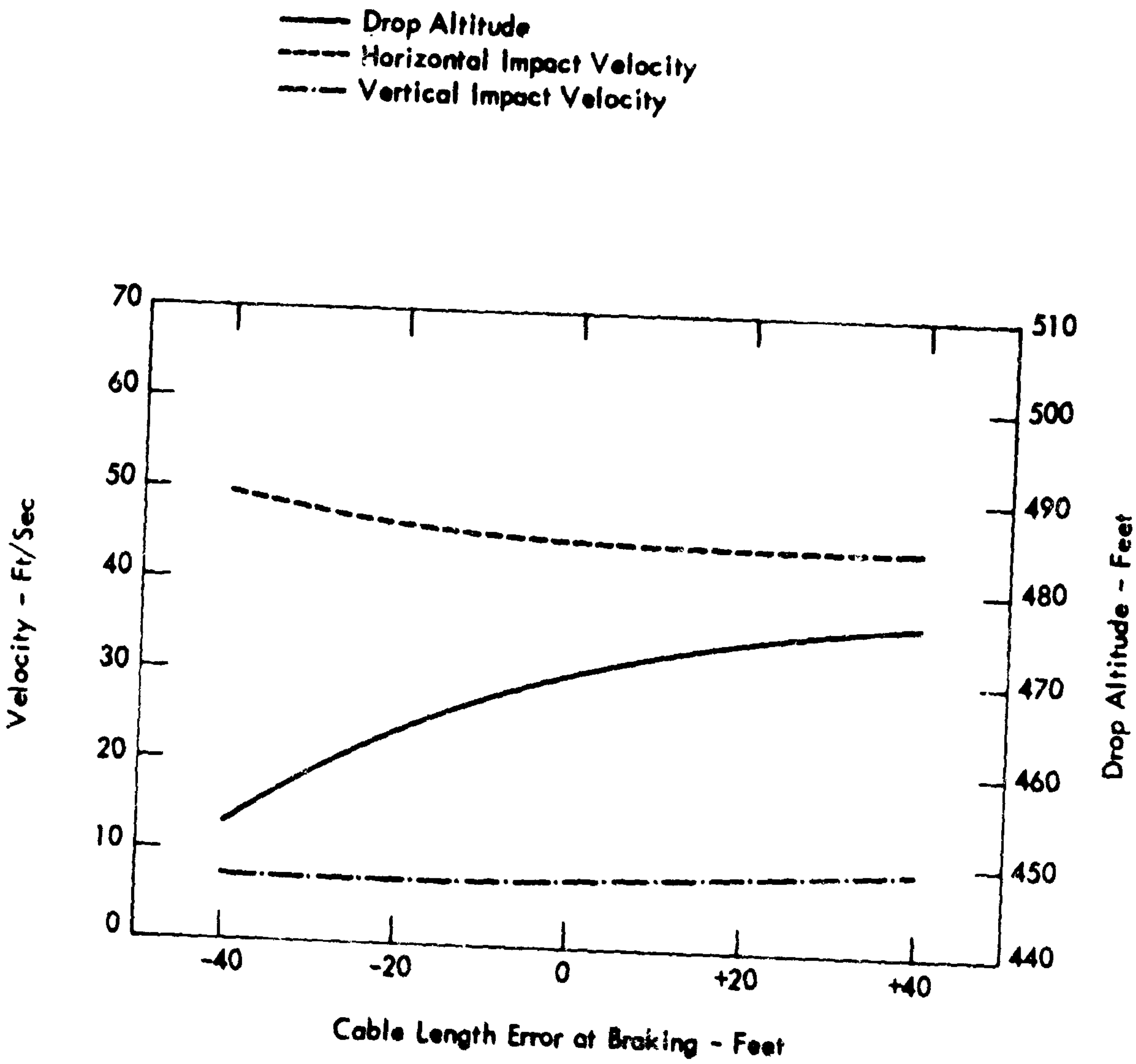

Figure 33 - Sensitivity to Cable Length at Braking

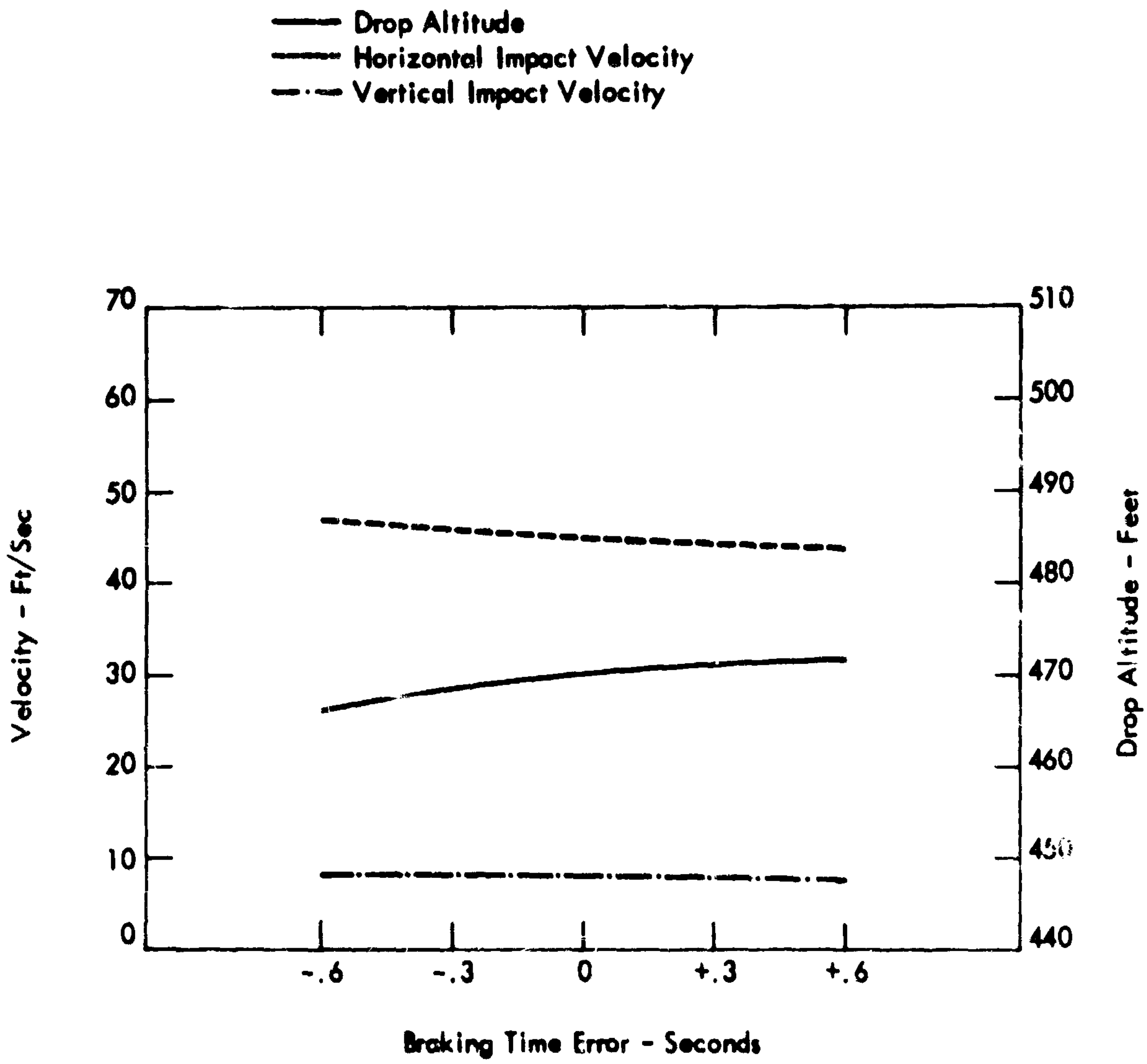

Figure 84 - Sensitivity to Braking Time

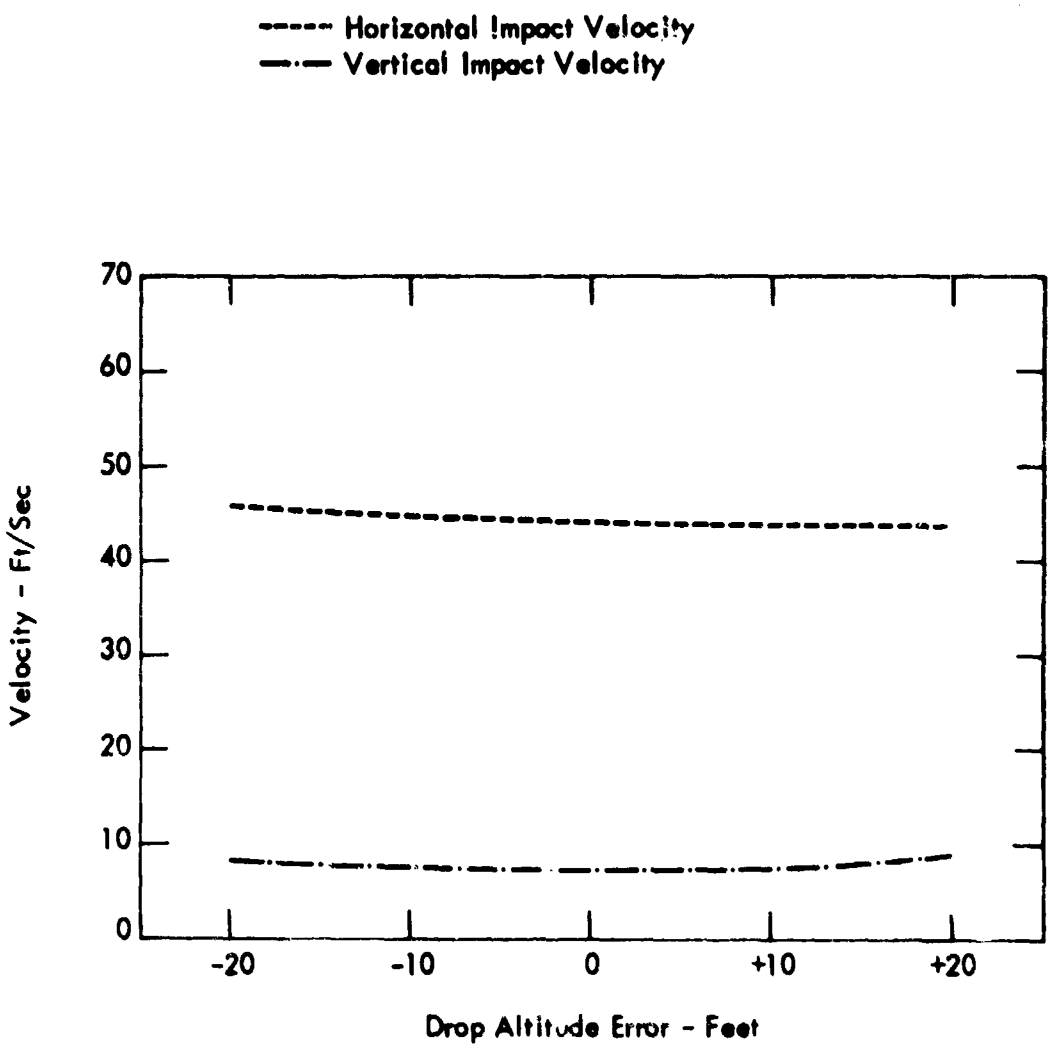

Figure [illegible] - Sensitivity to Drop Altitude

SIGNATURE

The Trolley system offers great advantage for concealing evidence of an airdrop. Whereas present airdrop systems leave on the drop zone the equipment used for retarding the speed of the unit drop weight and lowering it to the ground (rockets, parachutes, water twisters, etc.) and the honeycomb used for arresting vertical velocity, Trolley retrieves all such equipment into the drop aircraft. Not only does this clear the drop zone of such equipment, but it also permits reuse of these items.

The only items left on the drop zone are the unit drop weight, the drop platform, the rigging straps, and the Trolley slide assembly. The slide assembly will be quite small (about 30 inches long) and is easily disposed of. The remaining straps and platforms will result in a much smaller problem for clearing the drop zone than is presently experienced with airdrop systems.

COST

This section presents estimated costs of the following:

- o New Equipment
- o Cost of Added Equipment
- o Cost of Equipment used in Conventional Airdrop that is Deleted from Trolley Airdrop

Table XV gives the costs of equipment that is part of the Trolley system itself; Tables XVI through XXV give deleted and added costs of rigging for Trolley airdrop relative to conventional airdrop.

All of the items listed in Table XV stay with the aircraft or are retrieved into the aircraft after Trolley airdrop with the exception of the slide. The slide is reusable but it is released from the cable after airdrop. Therefore, none of the items in Figure 100 (with the exception of the slide) have to be repurchased or retrieved for additional airdrops. These non-recurring purchases are thus amortized over the life of the Trolley system.

Table XVI through XXV list equipment used in conventional airdrop that is deleted for Trolley airdrop, and they also list the additive equipment necessary. Associated costs and weights of each item are also listed. The 10 rigged loads presented are those that Trolley is capable of delivering as listed in Table III of the Dunlap information requirements document.

FINAL CONSIDERATIONS

Data presented in this memorandum are in accordance with the request made by Dunlap in its information requirements document. Those data requested were specific in nature; hence some of the capabilities of Trolley are not apparent in the results presented here. For example, Trolley has an inherent accuracy capability that allows very precise airdrop of equipment. These accuracy capabilities of Trolley are discussed in the Random Error and Accuracy Analyses and the Operational Analysis sections of the formal 240-day progress report dated 29 July 1966. In these sections of the progress report the small elliptical shape of the drop zone required for Trolley is described in detail. Of significant importance is that Trolley requires only a 180-foot long, 18-foot wide drop zone for a single drop when the aircraft is flying at 130 knots.

Item Description	Quantity	Average Unit Cost Dollars	High Estimate Dollars	Low Estimate Dollars
Slide	1	600	1,000	400
Guide Rail	1	500	800	400
Stop	1	45	75	25
Guide Pulley	2	35	50	20
Cable	1	2,000	2,400	1,800
Guillotine	1	250	300	225
22' Ringslot Parachute*	1	250	300	235
28' Ringslot Parachute*	1	370	420	350
35' Ringslot Parachute*	1	500	550	480
Winch Platform	1	500	700	400
Radar Altimeter	1	7,000	7,800	6,800
Winch	1	84,000	84,000	84,000
Trolley Equipment Cost		95,335	97,595	94,440

Note: The winch concept is within the state of the art and would not require any breakthrough in technology. However, Lockheed has little experience in estimating winch costs and does not feel qualified to pass judgment on these figures; hence no estimate of high and low costs was made.

*Only one parachute used per drop. The 28-foot parachute costs were used in arriving at the totals.

Table [illegible] - Cost of Peculiar Trolley Equipment

Rigging Load Number 1

M38A1, 1/4-Ton Utility Truck
Table XXI TM10-500-10

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
3040-273-8713	Adhesive, Paste	A.R.	2.50	5.0
1670-753-3928	Pad, Energy Dissipating (Honeycomb)			
	3 x 10 x 12	12	5.46	8.35
	3 x 12 x 12	10	5.42	7.25
	3 x 12 x 18	14	10.30	13.80
	3 x 12 x 96	8	34.70	47.00
1670-269-1107	Parachute, Cargo, 100 ft., G-11A	2	2300.00	500.0
1670-851-4574	Parachute, Cargo Extraction, 15 ft.	1	98.75	26.0
1670-897-4459	Cable, Release, Parachute Extraction	1	2.00	1.0
1670-753-3794	Cable, Release, 20 ft., (floor) (Riser Ext.)	2	28.80	1
1670-473-5115	Static Line Cargo Parachute	2	14.60	2
1670-473-5116	Strap, Parachute Release	1	1.90	1
NSN	Plywood, 3/4 x 48 x 60, (Parachute Stowage Platform)	1	8.00	50.
			2512.43	662.40

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3789	Sling, Cargo A/D, 8 ft., 2-loop	2	12.00	4
1670-753-3790	Sling, Cargo A/D, 9 ft., 2-loop	2	13.00	4
			25.00	8
	Net Savings Per Drop		2487.43	654.4

Current Rigged Unit Weight 4180 pounds, $W_R/W = 1.415$

Trolley Rigged Unit Weight 3530 pounds, $W_R/W = 1.195$

[illegible] - Rigging Cost, M38A1

Rigging Load Number 2

M37, 3/4-Ton, 4 x 4, Cargo Truck (Without Winch or Accompanying Load)
Table 4 (Column A) TM10-500-11

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
8040-273-8713	Adhesive, Paste	A.R.	2.50	5.0
1670-897-4459	Cable, Release, Parachute, Extraction	1	2.00	1
1375-862-6923	Cartridge, Time Delay, 20 sec.	2	5.00	1
1670-799-8596	Load Coupler, 8 spool	1	20.00	25
1670-269-1107	Parachute, G-11A	2	2300.00	500
1670-851-4574	Parachute, 15 ft. Extraction	1	98.75	26
1670-799-8494	Release, Cargo Parachute, 5000 lb.	2	120.00	20
1670-753-3794	20 ft. (2-loop)(Riser Ext.)	2	14.40	5
1670-473-5115	Static Line, Cargo Parachute	2	14.60	4
1670-473-5116	Strap, Parachute Release	1	1.90	2
8305-263-3591	Webbing, Type VIII (Para. Restraint Strap)	6 yd.	2.20	2
NSN	3/4 x 48 x 52 Plywood	1	8.00	50
1670-753-3928	Honeycomb Pad			
	3 x 12 x 12	10	5.42	7.4
	3 x 12 x 24	3	3.25	4.4
	3 x 12 x 30	2	2.71	3.7
	3 x 12 x 40	11	19.50	26.5
	3 x 12 x 48	2	4.34	5.9
	3 x 12 x 54	14	34.15	46.3
	3 x 12 x 48	6	13.00	17.6
			2671.72	752.80

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3791	11-ft. (2-loop) Sling	4	32.00	8.0
			32.00	8.0
	Net Savings Per Drop		2639.72	744.8

Current Rigged Weight 7409 pounds, $W_R/W = 1.305$

Trolley Rigged Weight 6671 pounds, $W_R/W = 1.175$

Table XVII - Rigging Cost, M37

Rigging Load Number 3

7000-Lb. Mass Load on 8-Ft. Modular (168 5-Gallon Cans) (4 A-22 Containers)
(Load Suspension)
TM10-500-12-3 Table Equipment Required (Added)

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3928	Pad, Honeycomb			
	3 x 17 x 96	1	6.50	8.8
	3 x 28 x 91	1	8.66	11.9
	3 x 36 x 91	2	25.00	33.8
	3 x 36 x 96	2	26.00	35.3
1670-269-1107	Parachute, 100 ft., G-11A	2	2300.00	500.0
1670-851-4574	Parachute, 15 ft., Extraction	1	98.75	26.0
			2464.91	615.8

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3790	Sling, 9-ft. (2-loop)	4	24.00	8
1670-753-3792	Sling, 11-ft. (2-loop)	1	8.00	2
			32.00	10
	Net Savings Per Drop		2432.91	605.8

Current Rigged Unit Drop Weight 8860 pounds, $W_R/W = \frac{8860}{7000} = 1.265$

Trolley Rigged Unit Drop Weight 8255 pounds, $W_R/W = \frac{8255}{7000} = 1.180$

Table XVIII – Rigging Cost, 7000-Pound Mass Load

Rigging Load Number 4

M101 3/4-Ton Cargo Trailer
Table 3 TM10-500-13

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
8040-273-8713	Adhesive, Paste, 1 gal.	1	5.00	10.0
1670-753-3928	Pad, Energy Dissipating			
	3 x 12 x 12	12	6.50	8.8
	3 x 12 x 32	18	26.00	33.8
	3 x 12 x 36	10	16.30	22.0
	3 x 12 x 42	1	1.90	2.6
	3 x 12 x 50	1	2.17	2.9
	3 x 12 x 53	1	2.44	2.9
	3 x 36 x 36	1	4.85	6.5
1670-269-1107	Parachute, Cargo, G-11A	2	2300.00	500.0
1670-851-4574	Parachute, Cargo Ext. 15 ft.	1	98.75	26.0
			2463.91	615.5

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3789	Sling, 8 ft. (2-loop)	4	24.00	8
			24.00	8
	Net Savings Per Drop		2439.91	607.5

Current Rigged Weight 5030 pounds, $W_R/W = \frac{5030}{3840} = 1.31$

Trolley Rigged Weight 4415 pounds, $W_R/W = \frac{4415}{3840} = 1.15$

Table XIX - Rigging Cost, M101

Rigging Load Number 5

M170 1/4-Ton Ambulance
Table XLV TM10-500-10

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
8040-273-6713	Adhesive, Paste, 1 gal.	1	5.00	10.0
1670-753-3928	Pad, Energy Dissipating			
	3 x 6 x 12	4	1.08	1.5
	3 x 10 x 12	18	9.74	13.2
	3 x 12 x 12	10	5.42	7.3
	3 x 12 x 16	4	2.71	3.5
	3 x 12 x 112	8	39.00	38.2
	3 x 16 x 20	2	2.17	2.9
	3 x 20 x 56	1	2.71	3.5
1670-269-1107	Parachute, Cargo, 100 ft., G-11A	2	2300.00	500.0
1670-851-4574	Parachute, Cargo Ext., 15 ft.	1	98.75	26.0
NSN	Plywood, 3/4 x 48 x 60	1	8.00	50.0
			2474.58	656.1

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3789	Sling, 8 ft. (2-loop)	2	12.00	4.0
1670-753-3790	Sling, 9 ft. (2-loop)	2	13.00	4.0
			25.00	8.0
	Net Savings Per Drop		2449.58	648.1

Current Rigged Weight 4400 pounds, $W_R/W = \frac{4400}{3287} = 1.34$

Trolley Rigged Weight 3748 pounds, $W_R/W = \frac{3744}{3287} = 1.14$

Table XX - Rigging Cost, M170

Rigging Load Number 6

105 mm Howitzer with 1800 Pounds Accompanying Load
Table 3 TM10-500-19

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
8040	Adhesive, Paste	A.R.	2.50	5.0
1670-753-3928	Pad, Energy Dissipation, (Honeycomb)			
	3 x 36 x 84	2	22.80	38.0
	3 x 18 x 36	6	15.20	19.1
	3 x 18 x 36	6	15.20	19.1
1375-862-6923	Cartridge, Time Delay, 20 sec.	3	7.50	1.0
1670-799-8596	Load Coupler, 8 spool	1	20.00	25.0
1670-269-1107	Parachute, Cargo, 100 ft., G-11A	3	3450.00	750.0
1670-687-5458	Parachute, Cargo, Ext., 22 ft.	1	235.00	42.0
8305-263-3591	Webbing, Nylon Type VIII	6 yds	2.00	2.0
NSN	Plywood, 3/4 x 48 x 60	1	8.00	50.0
			3778.20	951.2

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3789	Sling, 8 ft., 2-loop	2	12.00	4
1670-753-3790	Sling, 9 ft., 2-loop	2	13.00	4
1670-753-3791	Sling, 11 ft., 2-loop	2	24.00	4
1670-753-3794	Sling, 3 ft., 2-loop	2	9.10	4
			58.10	16
	Net Savings Per Drop		3720.10	935.2

Current Rigged Weight 8626 pounds, $W_R/W = \frac{8626}{7034} = 1.23$

Trolley Rigged Weight 7654 pounds, $W_R/W = \frac{7654}{7036} = 1.09$

Table XXI - Rigging Cost, 105 mm Howitzer

Rigging Load Number 7

M274, 1/2-Ton Infantry Light Weapons Carriers (4)
TM10-36-3-1 Appendix

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3928	Pad, Energy Dissipation Honeycomb			
	3 x 5 x 25	18	9.75	13.2
	3 x 5 x 10	8	1.63	2.4
	3 x 5 x 12	4	1.08	1.5
	3 x 12 x 29	36	48.80	63.0
	3 x 8 x 27	8	6.50	8.8
	3 x 8 x 25	8	7.05	9.4
	3 x 33 x 36	4	18.42	25.0
8040-273-8713	Adhesive, Paste (gallon)	1	5.00	10.0
1670-277-9803	Parachute, 64 ft., G-12D	3	1746.00	378.0
1670-269-1107	Parachute, 100 ft., G-11A	1	1150.00	250.0
1670-851-4574	Parachute, Cargo Ext., 15 ft.	1	98.75	26.0
			3092.98	787.30

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3791	Sling, 11 ft. (2-loop)	4	32.00	8.0
1670-753	Sling, 16 ft. (2-loop)	2	23.30	6.0
			55.30	14.0
	Net Savings Per Drop		3037.68	773.30

Current Rigged Weight 7160 pounds, $W_R/W = \frac{7160}{5280} = 1.356$

Trolley Rigged Weight 6368 pounds, $W_R/W = \frac{6368}{5280} = 1.208$

Note: Piggyback (top) load lands with basic (bottom) load as single unit with Trolley air drop system. Current air drop systems have piggyback separating and being lowered to ground by G-12D and G-11A cargo parachutes, respectively.

Table XXII- Rigging Cost, M274

Rigging Load Number 8

M151, 1/4-Ton Utility Truck (Truck Only)
Table IV TM10-500-10

Delete

FSN		Quantity	Total Cost, Dollars	Weight, Pounds
8040-273-8713	Adhesive, Paste, 1 gal.	1	5.00	10.0
1670-753-3928	Pad, Energy Dissipating, Honeycomb			
	3 x 6 x 8	28	5.10	7.0
	3 x 12 x 12	6	3.25	4.4
	3 x 12 x 20	6	5.42	7.3
	3 x 24 x 48	3	13.00	17.6
1670-269-1107	Parachute, 100 ft., G-11A	1	1150.00	250.0
1670-851-4574	Parachute, Cargo Ext., 15 ft.	1	98.75	26.0
NSN	Plywood, 3/4 x 18 x 20	1	1.14	7.0
	3/4 x 24 x 48	1	3.20	20.0
			1284.86	349.3

Add

1670-753-3789	Sling, 8 ft., 2-loop	2	12.00	4
1670-753-3790	Sling, 9 ft., 2-loop	2	13.00	4
			25.00	8
	Net Savings Per Drop		1259.86	341.3

Current Rigged Unit Weight 3088 pounds, $W_R/W = \frac{3088}{2400} = 1.289$

Trolley Rigged Unit Weight 2747 pounds, $W_R/W = \frac{2747}{2400} = 1.145$

Table [illegible] - Rigging Cost, M151

Rigging Load Number 9

M416, 1/4-Ton Cargo Trailer with Accompanying Load
Appendix II TM10-500-61-3

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-269-1107	Parachute, Cargo, 100 ft., G-11A	1	1150.00	250.0
1670-851-4574	Parachute, Extraction, 15 ft.	1	98.75	26.0
			1248.75	332.2

Add

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
1670-753-3789	Sling, 8 ft. (2-loop)	4	24.00	8
			24.00	8
	Net Savings Per Drop		1224.75	324.2

Current Rigged Unit Weight 2520 pounds, $W_R/W = \frac{2520}{1870} = 1.348$

Trolley Rigged Unit Weight 2196 pounds, $W_R/W = \frac{2196}{1870} = 1.173$

[illegible] - Rigging Cost, M416

Rigging Load Number 10

M35 2-1/2 Ton Cargo Truck with 1500 Pound Accompanying Load
TM10-500-20

Delete

FSN	Nomenclature	Quantity	Total Cost, Dollars	Weight, Pounds
8040-273-8713	Adhesive, Paste, 1 Gal.	1	5.00	10
1375-862-6923	Cartridge, Time Delay, 20 sec.	6	15.00	2
1670-799-8597	Load, Coupler, 12 Spool	1	30.00	35
1670-753-3928	Pad, Energy Dissipating, Honeycomb			
	3 x 6 x 12	6	1.63	2.9
	3 x 6 x 30	6	4.06	11.2
	3 x 12 x 12	5	2.71	3.5
	3 x 12 x 18	1	.81	1.2
	3 x 12 x 20	7	4.23	5.6
	3 x 12 x 30	5	6.75	9.1
	3 x 12 x 36	13	21.10	29.4
	3 x 12 x 40	1	1.73	2.3
	3 x 12 x 42	12	22.80	30.8
	3 x 12 x 34	12	29.30	39.6
	3 x 12 x 60	12	32.50	44.1
	3 x 18 x 18	18	21.70	29.4
	3 x 20 x 30	5	32.50	44.1
1670-269-1107	Parachute, 100 ft., G-11A	6	6900.00	1500.0
1670-687-5459	Parachute, Cargo Ext., 28 ft.	1	350.00	100.0
1670-799-8494	Release, Cargo Parachute, 5000 lb.	2	140.00	20.0
1670-473-5115	Static, Line Cargo Parachute	2	14.60	2.0
NSN	Lumber, 3-1/8 x 4 x 9	2	.50	4.0
NSN	Plywood, 3/4 x 19 x 65	1	8.00	50.0
			7644.92	1976.2

Add

	Sling, 16 ft., 2-loop	2	16.00	4
	Sling, 11 ft., 2-loop	2	23.30	4
			39.30	8
	Net Savings Per Drop		7605.62	1968.2

Current Rigged Weight 17,464 (changed from 18,364) pounds, $W_R/W = \frac{17,464}{14,380}$

$= 1.215$

Trolley Rigged Weight 15,508 pounds, $W_R/W = \frac{15,508}{14,380} = 1.08$

Table XXV - Rigging Cost, M35

The Operational Analysis section also shows that Trolley requires only minor changes to present training, rigging, and operational procedures. This, combined with little or no change to the drop aircraft, makes the introduction of Trolley into the Army inventory a relatively simple matter.

The rigging requirements for Trolley airdrop are substantially reduced compared to conventional airdrop. Significant cost and weight savings are realized as noted in the cost section of this document. However, the Economy and Operational Analysis sections of the 240-day progress report contain more detailed information on the cost analysis and its impact and on the rigging weight saved.

The heaviest load item in the Dunlap report (Table II) that Trolley can deliver is the M37 vehicle which weighs 7187 pounds. Hence Trolley's ability to deliver a full 10,000-pound package is overlooked. Complete data on system performance while a 2000 to 10,000-pound package is being delivered are found in the Analog Results section of the 240-day progress report. It is important to note that loading studies of the airborne movement of major Army units show that over 90-percent of the items to be moved weigh less than 10,000 pounds each. Thus Trolley has the ability to deliver most of the items which must be moved.

The Functional Analysis section of the 240-day progress report contains discussions of the maintainability and simplicity of Trolley. The ease of maintenance and the simplicity of the equipment are important factors for evaluating the operational desirability of Trolley.

The data presented herein show the results of a conceptual study which considered drop weights from 2000 to 10,000 pounds and drop speeds of 110 to 150 knots. As such, the results are not optimized to any specific conditions. If a nominal drop speed were chosen, say 120 knots, then a variation of the other drop parameters (extraction acceleration, winch braking time, initial cable length, etc.) could be accomplished to optimize impact velocities and drop altitude. Further reduction which could be expected in these items would improve the overall desirability of the Trolley Airdrop System.

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13. ABSTRACT

The Lockheed Trolley Low Altitude Airdrop Concept employs a towed parachute to maintain tension in a long cable from which a load may be suspended until it contacts the ground. After it is extracted by the force of the parachute, the load slides beneath the cable until it contacts the ground. Rate of descent is controlled by a winch in the aircraft that reels in the cable as needed to minimize impact velocity.

This preliminary concept-oriented investigation was undertaken to determine the feasibility of developing this system for operational use. The study consists of analytical evaluation of the operational parameters, limited component testing, and consideration of basic hardware requirements. Finalization of hardware design is not within the scope of this report. Digital and analog computer simulations of Trolley airdrop are among the analytical methods employed. Two tests of a parachute towed on a Trolley cable behind a C-130 aircraft are evaluated. Laboratory tests of certain components are analyzed with respect to flight safety.

Results of this study indicate no problems which preclude the development of the Trolley airdrop concept into an operational system for airdropping individual loads of 2,000 to 10,000 pounds from a C-130 below 500 feet. Comparison of Trolley to conventional airdrop shows: (1) costs are reduced, (2) accuracy is improved, (3) impact velocities are lower, (4) rigging is simplified. However, the system is unsuitable for mass assault where several unit loads must be dropped per aircraft pass.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Accuracy	8					
Cost	8					
Lending impact	8					
Assembling	8					
Compatibility	8					
Low altitude	9					
Air-drop operations	9					
Trolleys	10					

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